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CANADA'S 50 BEST MANAGED PRIVATE COMPANIES

WATER QUALITY GUIDELINES FOR METHYL TERTIARY-BUTYL ETHER (MTBE)

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EXECUTIVE SUMMARY

This report provides methyl tertiary-butyl ether (MTBE) water quality guidelines for the province of British Columbia. Human drinking water guidelines were developed based on a summary of guidelines from other jurisdictions. Freshwater aquatic life, marine aquatic life, irrigation, and livestock watering guidelines were developed using toxicological effects data and protocols from the Canadian Council for Ministers of the Environment.

MTBE is a gasoline additive that is volatile in the atmosphere and mobile in groundwater. The primary source of MTBE in the environment is from leaking underground storage tanks containing reformulated gasoline. Automobile fuel blended with an oxygenate additive such as MTBE is known as reformulated gasoline. Laboratory microcosms, field-scale tests, and empirical site data have shown that MTBE biodegrades slowly in both aerobic and anaerobic environments.

Proposed MTBE water quality guidelines are summarized in Table 2 in this report. The human drinking water guideline (0.02 mg/L) was based on taste and odour. Recreational water quality guidelines from other jurisdictions were not found and, thus, this guideline was set at the human drinking water value. Freshwater aquatic life, marine aquatic life, and livestock watering guidelines were 3.4 mg/L, 0.44 mg/L, and 11 mg/L, respectively. No studies were available on the toxicity of MTBE to terrestrial plants and, therefore, an irrigation guideline could not be developed.

Collection of water samples for MTBE analysis should follow protocols used for volatile organic compounds. GC/PID can be used as a screening method. However, this method is prone to false positives and interference problems. Should a detection occur using GC/PID, confirmatory analysis by GC/MS would be required. GC/MS is the recommended methodology for MTBE analysis.

1. INTRODUCTION

This report presents water quality guidelines developed for methyl tertiary-butyl ether (MTBE) for the province of British Columbia. The work was completed by Komex International Ltd., under contract #WMB01-032 (the Contract), to the British Columbia Ministry of Environment, Lands & Parks, Water Management Branch.

1.1 Background

The 1990 Clean Air Act Amendment in the United States required fuel oxygenates to be added to gasoline in some metropolitan areas to reduce atmospheric concentrations of carbon monoxide, carbon dioxide, and ozone. MTBE is the most commonly used fuel oxygenate because of its low cost, ease of production and transfer, and blending characteristics (*e.g.*, Mormile *et al.*, 1994). MTBE has become an important groundwater contaminant because of its mobility (Garrett *et al.*, 1986; Environment Canada, 1993; Davidson, 1995), recalcitrant nature (Moller and Arvin, 1990; Yeh and Novak, 1991; Mormile *et al.*, 1994), and potential toxicity (USEPA, 1993; ATSDR, 1994; HEI, 1996).

The use of MTBE has become controversial, due primarily to issues with contaminated groundwater supplies. California banned the use of MTBE, effective 31 December 2002. MTBE has been used in British Columbia since 1995.

1.2 Scope of Work

The scope of work for this project, detailed in the Contract, was to:

- identify, review, describe, and assess all available literature related to MTBE in raw waters (*i.e.*, causes of release, health effects, guidelines, and other potentially useful information);
- review analytical methods for the analysis of MTBE in water and propose a methodology that achieves the detection limit, accuracy, and precision required for compliance with the recommended guidelines;
- recommend sampling protocols and other monitoring considerations that may be pertinent;
- compile and recommend guidelines from other jurisdictions to use in the assessment of MTBE in drinking water and recreational waters;
- develop scientifically-based water quality guidelines to protect water quality in BC, for uses including freshwater and marine aquatic life, irrigation, and livestock watering;
- provide guidance on research needs and data gaps; and,
- prepare a technical report using a similar format to other criteria/guidelines in BC.

1.3 Protocols

Environmental quality guidelines for MTBE were developed using the following protocols developed by the Canadian Council of Ministers of the Environment (CCME):

A Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life. (CCME, 1999).

Protocols for Deriving Water Quality Guidelines for the Protection of Agricultural Water Uses. (CCME, 1999).

For ease of reference in this document, the phrase "the Protocol" refers to whichever of the above documents is applicable. Note that the two water Protocols listed above (Aquatic Life, and Agricultural Water Uses) were originally published as CCME (1991), and CCME (1993), respectively, and were reproduced with minor changes in CCME (1999).

The above Protocols define two types of guidelines. Full guidelines reflect a dataset which is of high quality and sufficiently complete to allow a high degree of confidence in the resulting guideline. Interim guidelines are derived from a dataset which was not sufficient to allow derivation of a Full guideline, but conformed to a less strict set of requirements. For the purposes of this document, a third type of guideline was introduced. "Preliminary" guidelines are derived from a dataset that did not meet all the requirements for Interim guidelines. Preliminary guidelines were derived where it was felt that a guideline derived from a limited dataset was more useful than no guideline at all. Once sufficient toxicological data become available, it is anticipated that preliminary guidelines will be updated to Interim or Full status.

1.4 Toxicity Data Search

An extensive literature search was conducted to identify toxicity data for MTBE to mammals, marine and freshwater aquatic life, terrestrial invertebrates, plants, and other organisms. Databases and other information sources searched included Biological Abstracts, TOXLINE, AGRICOLA, ECOTOX, MEDLINE, Uncover Web, SETAC, and Springer Link. Keywords used for the search were "methyl tertiary-butyl ether and MTBE".

2. METHYL TERTIARY-BUTYL ETHER IN THE ENVIRONMENT

2.1 Production and Uses

There are no natural sources of MTBE. There was no production in Canada before 1992. Production began in 1992 by Alberta Envirofuels, Inc., Edmonton, Alberta, with an estimated 500,000 tonnes per year (Solsberg, 1991). Most of the MTBE produced was shipped by rail from Edmonton to Kitimat, BC and then by ocean tanker to US.

Canadian importation of MTBE for the purpose of blending with unleaded gasoline from 1986 to 1990 was between 7000 and 25,000 tonnes per year. Over the past six years MTBE has been used at one time or another in all areas of Canada. If and when it was used it was blended to a maximum 15% volume in premium and super premium grades. Because some mid-grade products are a blend of 50% premium and 50% regular they too could have contained MTBE if and when MTBE was blended. Based on preliminary information from the fourth quarter 1999, Federal "Benzene in Gasoline Report" the average concentrations of MTBE in Canada is 0.35 vol.%. approximately one-tenth that in the USA.

The last CPPI member company to use MTBE in gasoline in Western Canada ceased doing so, including all gasoline sold or exchanged to others, as of October 2000. No companies have plans to again use MTBE in gasoline in Western Canada.

2.2 Chemical and Physical Properties

.MTBE (CAS Registry Number 1634-04-4) is an aliphatic ether. Representative chemical and physical properties of MTBE are summarized in Table 1. Synonyms include:

- 2-methoxy-2-methylpropane;
- 2-methyl-2-methoxypropane;
- Methyl 1, 1-dimethylethyl ether; and,
- *tert*-butyl methyl ether.

MTBE is volatile (vapour pressure is 33 kPa at 25°C) and has a high aqueous solubility (pure phase ~40,000 mg/L). MTBE has a specific gravity of 0.74 (20/4 °C). The organic carbon partition coefficient (log Koc) for MTBE is approximately 0.94 (Table 1). This indicates little adsorption of MTBE to aquifer material, which is consistent with field observations. Thus, little to no attenuation of MTBE is expected in a saturated medium with typical organic carbon contents. The octanol/water partition coefficients (log Kow) for MTBE is approximately 1.6 (Table 4). This indicates that MTBE is not likely to accumulate in human or animal fat tissue.

2.3 Organoleptic Thresholds

MTBE is reported to have a distinctive, terpene-like odour in air (Gilbert and Calabrese, 1992). A number of different studies have reported taste and order thresholds for MTBE (Table 1).

The American Petroleum Institute taste and odour thresholds of approximately 39 ppb and 53 ppb, respectively (API, 1993). Young *et al.* (1996) reported taste and odour thresholds of 40 ppb and 15 ppb, respectively. The Orange County Water District in California performed a study on threshold odor concentrations of MTBE. That study, reported in Shen *et al.* (1997), found geometric means of 13.5 to 43.5 ppb, indicating that half of the panelists detected MTBE at those levels. Shen *et al.* (1997) also demonstrated that MTBE odour may be detected at levels as low as 2.5 ppb. However, as a lower concentration was not tested, it is possible that the odour threshold could be less than 2.5 ppb for some individuals.

2.4 Sources of MTBE in the Environment

A major source of MTBE in the environment is from leaking underground storage tanks containing reformulated gasoline (Squillace *et al.*, 1996). Reformulated gasoline commonly contains between ~10% to 15% MTBE (volume/volume). MTBE is used by some gasoline retailers in Canada and has been used by some gasoline retailers in British Columbia since 1995. Another localized source of MTBE in the environment is atmospheric release from refining/blending facilities (NPRI, 2000).

The United States Geological Survey initiated a national survey in 1991 of groundwater quality under the National Water Quality Assessment (NAWQA) program (Squillace *et al.*, 1996). This survey, which focused on the occurrences and possible sources of MTBE in groundwater, showed that 27% of the shallow wells sampled in urban areas had MTBE concentrations >0.0002 mg/L and that 1.3% had concentrations that exceeded 0.020 mg/L.

In a recent survey of groundwater wells in Washington state, MTBE was identified in 30 of 62 sites (48 percent). Fifteen of the sites had MTBE concentrations greater than the USEPA's national drinking water advisory level of 0.020 mg/L.

In November 2000, BC MELP analyzed MTBE in water samples collected at 59 groundwater wells. MTBE was detected in one sample.

Environment Canada's Aquatic Sciences Section participated in a survey with the US Geological Survey in 1997 of the shallow Abbotsford-Sumas Aquifer, which is located in southwestern BC, near the US border. The survey tested for some 200 chemicals and found trace amounts of MTBE

in a section of the aquifer; specifically, in 2 of 9 wells tested over a 10 km section of the aquifer. The levels were below the quantification limits of the instruments used (USGS, 1999).

2.5 Biodegradation

Laboratory microcosms, field-scale tests, and empirical site data have shown that MTBE biodegrades slowly in both aerobic and anaerobic environments (Yeh and Novak, 1995; Sulflita and Mormile, 1993; Mormile *et al.*, 1994). The poor biodegradation of MTBE has been attributed to the stable and unreactive ether bond, the inability of MTBE to be transported into cells, and/or the lack of existing enzyme activities that can attack the ether bond (Salinitro *et al.*, 1994). The main breakdown products of MTBE biodegradation include formaldehyde and tertiary-butyl alcohol (*e.g.*, Clary, 1997 and references therein).

With respect to development of water quality guidelines for freshwater and marine aquatic life, MTBE can be considered a "persistent variable" because it has a biodegradation half-life of greater than 8 weeks. Howard *et al.* (1991) report a biodegradation half-life ranging from four weeks to six months for the surface water environment.

3. WATER GUIDELINES FOR METHYL TERTIARY-BUTYL ETHER

The water quality guidelines for MTBE developed below are summarized in Table 2. Human drinking water guidelines were developed based on a summary of guidelines from other jurisdictions. Freshwater aquatic life, marine aquatic life, irrigation and livestock watering guidelines were developed using applicable CCME protocols and toxicity data. Details of the Protocol data requirements in terms of data quality and quantity are discussed below.

3.1 Water Guidelines From Other Jurisdictions

3.1.1 Drinking Water

3.1.1.1 Review of Available Information

A review of information from regulatory agencies worldwide was completed to determine what guidelines were being used by other jurisdictions for acceptable levels of MTBE in drinking water. Water quality guidelines have not been developed by the Canadian federal government. or provincial regulators. The only drinking water quality guideline found for Canada was in Ontario,

which reports a value of 0.70 mg/L in "Guideline for use at Contaminated Sites". This guideline does not consider aesthetics due to low odor and taste thresholds for MTBE.

Drinking water guidelines for federal and state jurisdictions in the U.S. are summarized in Table 3. Three main endpoints have been used by various jurisdictions in guideline development: 1) taste and odour; 2) health effects, considering MTBE as a carcinogen; and 3) health effects, considering MTBE as a non-carcinogen. These approaches are discussed further below.

The United States Environmental Protection Agency (USEPA, 1997) has issued a drinking water advisory for MTBE. This document recommends a range of 0.02 mg/L to 0.04 mg/L based on taste and odour thresholds. Thirteen American states have a guideline that is either based, or assumed to be based, on the taste and odour threshold. Most of these states use a value within, or close to, the range given by the USEPA (1997) (Table 3). California has issued a secondary maximum contaminant level of 0.005 mg/L, to protect the taste, odour and/or appearance of drinking water (Ca DHS, 2001).

Six states have calculated health-based guidelines considering MTBE a carcinogen (Table 3). New York and California calculate the most conservative guidelines (0.010 mg/L, and 0.013 mg/L, respectively). Maine, Massachusetts, New Hampshire, and New Jersey calculate guidelines that range from 0.035 mg/L to 0.070 mg/L.

Six states have calculated health-based guidelines by considering MTBE a non-carcinogen. The guidelines calculated by these states range from 0.035 mg/L (Arizona) to 0.52 mg/L (Louisiana) (Table 3). Other jurisdictions either have not made the basis of their guideline available, or have not adopted a guideline at the present time (Table 3).

3.1.1.2 Recommended Guideline

The health-based guidelines discussed above used a variety of methodologies to derive a drinking water guideline from a number of toxicological studies. Only two states, New York and California calculated guidelines (0.010 mg/L, and 0.013 mg/L, respectively) that were below the lower end of the taste and odour threshold (0.020 mg/L) published by USEPA (1997).

The health-based drinking water guideline was recalculated using receptor parameters from the Canadian Council for Ministers of the Environment, the California Environmental Protection Agency cancer slope factor (0.0018 $(mg/kg\text{-}d)^{-1}$), and assuming a lifetime exposure weighted for five human life stages and a maximum acceptable excess cancer risk of 1 in 1,000,000. The recalculated health-based MTBE human drinking water guideline is 0.021 mg/L.

Based on procedures and parameters normally used in British Columbia, the most sensitive endpoint for drinking water is the taste and odour threshold. It is therefore recommended that the lower end of the range for taste and odour threshold published by USEPA (1997) be adopted, and that the drinking water guideline be set at 0.020 mg/L. This guideline is identical to the health-based drinking water guideline protective of the public for a maximum acceptable excess cancer risk of 1 in 1,000,000.

3.1.2 Recreational Uses

No guidelines for acceptable levels of MTBE in water for recreational uses were found from any jurisdictions. It is proposed that the recreational water guideline be equivalent to the drinking water guideline (*i.e.*, 0.020 mg/L), based on the taste and odour threshold.

Consideration of multiple routes of exposure (*i.e.*, ingestion, inhalation, and dermal absorption) was not given in proposing a recreational water guideline equivalent to the drinking water guideline. However, the exposure frequency in a recreational setting is considerably lower than a domestic setting. For this reason, the drinking water guideline (*i.e.*, 0.020 mg/L) will be fully protective of recreational exposure.

3.2 Freshwater Aquatic Life Guideline

3.2.1 Toxicological Behaviour and Effects

Freshwater aquatic data are summarized in Table 4. Four main groups of freshwater aquatic biota are identified (vertebrates, invertebrates, plants, and other biota). The data for each are discussed in the following Sections.

3.2.1.1 Vertebrates

A total of 23 data points were available (Table 4) from 13 studies for 6 species of freshwater aquatic vertebrates: rainbow trout (*Oncorhynchus mykiss*), fathead minnow (*Pimephales promelas*), Japanese medaka (*Oryzias latipes*), common frog (*Rana temporaria*), carp (*Leuciscus idus melanotus*), and bluegill (*Lepomis macrochirus*). Test durations varied from 1 to 7 days, and thus would be considered acute studies, since the test duration is not a significant fraction of the lifespan of the organism. Endpoints were mostly survival, with the exception of two tests that considered growth/development endpoints. Reported LC50 values ranged from 672 mg/L (fathead minnow) to 2,500 mg/L (frog). The LOEC for fathead minnow growth was 388 mg/L.

3.2.1.2 Invertebrates

Seven studies considered the toxicity of MTBE to 4 species of aquatic invertebrates (Table 4): two species of water fleas *(Daphnia magna* and *Ceriodaphnia dubia)*, and a rotifer *(Brachionus calyciflorus)*. The majority of the data were from acute lethality tests, with durations ranging from 24 hours to 96 hours. Reported LC50 values for these tests ranged from 340 mg/L (*C. dubia* 48-hour survival) to 1,118 mg/L (*D. magna* 24-hour survival). Chronic studies considered reproduction and survival in *C. dubia*. The lowest LOEC reported for a chronic study was 342 mg/L (*C. dubia* 5-day reproduction).

3.2.1.3 Plants

Two studies (Table 4) considered the toxicity of MTBE to the green alga *Selenastrum capricornutum*. Rousch and Sommerfeld (1998) report a LOEC of 4,789 mg/L for a growth endpoint at 5 days in this species. Ben Kinney *et al.* (1994; as cited in U.C. Davis, 1998), reported an EC50 of 184 mg/L for an unknown endpoint. However, the original study was not available to determine the endpoint and the study's relevance.

3.2.1.4 Other Biota

Other aquatic biota include all aquatic organisms not included in the animal or plant kingdoms. This covers organisms from the kingdoms Monera, Protista and Fungi. Rousch and Sommerfeld (1998) report a LOEC of 2,868 mg/L for a growth endpoint at 3 days in the diatom *Navicula pelliculosa*, and a LOEC of 2,489 mg/L for a growth endpoint at 5 days in the cyanobacteria *Synechococcus leopoliensis* (Table 4). Kado *et al.* (1998) report a 48 hour growth LOEC of 7.4 mg/L for *Salmonella typhimurium*. However, *S. typhimurium* is not a typical freshwater species, and thus, was not included in guideline development.

3.2.2 Data Analysis

Freshwater aquatic life guidelines were developed using the Protocol ("A *Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life*; CCME, 1999). This Section summarizes the requirements of the Protocol and discusses the available dataset in terms of these requirements. The toxicological dataset was summarized in Table 4, and discussed above.

The Protocol defines: (1) the requirements for a toxicological study to be acceptable for guideline derivation (data quality); (2) the minimum required dataset for Full and Interim guideline development (data quantity); and (3) the process for deriving guidelines. The following

paragraphs provide a summary of the requirements of the Protocol, and assess the toxicological dataset.

3.2.2.1 Data Quality

The data quality requirement in the Protocol may be summarized as follows. For a toxicological study to be considered "Secondary Data", all relevant environmental variables (*e.g.*, temperature, pH, hardness, dissolved oxygen, etc.) should be measured and reported, and the survival of controls must be reported. In addition, for data to be considered "Primary Data", tests must employ currently acceptable practices, concentrations must be measured at the beginning and end of a test, and, in general, dynamic (*i.e.*, flow-through) tests are required. Data that do not conform to the requirements for Primary or Secondary Data are "Unacceptable Data".

The toxicological dataset is summarized in Table 4 and classified as Primary, Secondary, and Unacceptable. It should be noted that studies classified as "Unacceptable Data" may, in fact, represent acceptable (*i.e.*, Primary or Secondary) data, but insufficient information was available to confirm this. According to the Protocol only Primary or Secondary Data can be used in the derivation of Interim guidelines.

3.2.2.2 Data Quantity

The minimum requirements for an Interim freshwater aquatic life guideline is as follows. At least two studies on freshwater fish species, and at least two studies on freshwater invertebrate species are required. The tests may be acute or chronic. One of the fish must be a cold water species, and two different classes of invertebrates must be represented, one of which includes a planktonic species resident in North America (*e.g.*, daphnid).

The Protocol requirements for the Interim guidelines were met by the Primary and Secondary Data in Table 4. The acute tests on rainbow trout and fathead minnow fulfill the requirement for tests of two freshwater fish species, with the rainbow trout fulfilling the requirement for a cold water species. Acceptable test results were available for three species of invertebrate: *Daphnia magna* and *Ceriodaphnia dubia*, representing the class Branchiopoda of the phylum Arthropoda and *Brachionus caliciflorus*, representing a class of the phylum Rotifera. Accordingly, the requirement for data from two species of invertebrates from different classes was met.

3.2.3 Guideline Derivation

The Protocol defines procedures for deriving guidelines from chronic or acute data. Guidelines were calculated from both acute and chronic data, and the lower value was adopted as the freshwater aquatic life guideline. A guideline can be calculated from chronic data, by using the

lowest LOEC from the most sensitive endpoint of the most sensitive lifestage of the most sensitive species, multiplied by a safety factor of 0.1 to give the freshwater aquatic life guideline. The lowest chronic LOEC for Primary or Secondary Data in this dataset is 342 mg/L for the 5 day reproduction endpoint for *Ceriodaphnia dubia*. This yields a guideline value of 34 mg/L.

A guideline can also be calculated from acute data, by using the lowest LC50 or EC50 value, and multiplying by an "application factor" of 0.01 for persistent variables. MTBE is assumed to have a biodegradation half-life of greater than 8 weeks, and thus is considered a persistent variable as discussed in Section 2.3. The lowest LC50 in the acute dataset is 340 mg/L for 48 hour *C. dubia* survival (Hockett, 1997b). Multiplying this value by an application factor of 0.01 gives a guideline of 3.4 mg/L. This value is lower than the guideline calculated from the chronic dataset, and thus the Interim freshwater aquatic guideline for MTBE is 3.4 mg/L (Table 2).

3.3 Marine Aquatic Life Guideline

3.3.1 Toxicological Behaviour and Effects

Marine aquatic data are summarized in Table 5. Four main groups of marine aquatic biota are identified (vertebrates, invertebrates, plants, and other biota). The data for each are discussed in the following Sections.

3.3.1.1 Vertebrates

A total of 4 data points were available (Table 5) from 4 studies for 3 species of marine aquatic vertebrates: sheepshead minnow (*Cyprinodon variegatus*), bleak (*Albernus alburnus*), and inland silverside (*Menidia beryllina*). Test durations varied from 1 to 4 days, and thus were considered acute, based on the test duration not being a significant fraction of the lifespan of the organism. All tests considered the survival endpoint. Reported LC50 values ranged from 574 mg/L (inland silverside) to >2,500 mg/L (sheepshead minnow).

3.3.1.2 Invertebrates

Six studies considered the toxicity of MTBE to 4 species of marine aquatic invertebrate (Table 5): two specific opossum shrimp *(Neomysis mercedis* and *Mysidopsis bahia),* a copepod *(Nitocra spinipes),* and an amphipod *(Chaetogammarus marinus).* All the data were acute lethality tests, with test durations being 96 hours except for one test where this information was not available. Reported LC50 values for these tests ranged from 44 mg/L (*M. bahia* 96 hour survival) to >10,000 mg/L (*N. spinipes,* 96 hour survival).

3.3.1.3 Plants

No toxicity data for marine aquatic plants were available.

3.3.1.4 Other Biota

Other aquatic biota include all aquatic organisms not included in the animal or plant kingdoms. This covers organisms from the kingdoms Monera, Protista, and Fungi. The only toxicity data for other biota were for marine bacterium Photobacterium phosphoreum (Microtox™). Gupta and Lin (1995) reported a 15 minute EC50 value of 31 mg/L.

3.3.2 Data Analysis

Marine aquatic life guidelines were developed using the Protocol ("A *Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life*; CCME, 1999). This Section summarizes the requirements of the Protocol and discuss the available dataset in terms of these requirements. The toxicological dataset was summarized in Table 5, and discussed above.

The Protocol defines: (1) the requirements for a toxicological study to be acceptable for guideline derivation (data quality requirement); (2) the minimum required dataset for Full and Interim guideline development (data quantity requirement); and (3) the process for deriving guidelines. The following paragraphs provide a summary of the requirements of the Protocol, and assess the toxicological dataset.

3.3.2.1 Data Quality

The data quality requirement in the Protocol may be summarized as follows. For a toxicological study to be considered "Secondary Data", all relevant environmental variables (*e.g.*, temperature, pH, hardness, dissolved oxygen, etc.) should be measured and reported, and the survival of controls must be reported. In addition, for data to be considered "Primary Data", tests must employ currently acceptable practices, concentrations must be measured at the beginning and end of a test, and, in general, dynamic (*i.e.*, flow-through) tests are required. Data that do not conform to the requirements for Primary or Secondary Data are "Unacceptable Data".

The toxicological dataset was summarized in Table 5 and data were classified as Primary, Secondary, and Unacceptable. It should be noted that studies classified as "Unacceptable Data" may, in fact, represent acceptable (*i.e.*, Primary or Secondary) data, but insufficient information was available to confirm this. According to the Protocol only Primary or Secondary Data can be used in the guideline derivation process.

3.3.2.2 Data Quantity

The Protocol requirement for the quantity of data needed for Interim marine aquatic life guidelines may be summarized as follows. At least two studies on marine fish species, and at least two studies on marine invertebrate species are required. The tests may be acute or chronic. One of the fish must be a temperate species, and two different classes of invertebrates must be represented, one of which is a temperate species.

The Protocol requirements were not met by the Primary and Secondary Data in Table 5, as only one fish species is represented, and the two invertebrate species are in the same class. Accordingly, no CCME guideline can be calculated for marine aquatic life for MTBE. However, it may be useful to have a preliminary marine aquatic guideline until further data can be collected, or further information for existing data becomes available. Accordingly a preliminary guideline was calculated, based on the Primary, Secondary, and Unacceptable data in Table 5. Note that the Microtox™ data were not included in the guideline derivation process, as they may not represent a typical toxicological response in marine aquatic life.

If the Primary, Secondary, and Unacceptable data from Table 5 are used, then the Protocol data quantity requirements can be met. The fish data requirement was met by three species of fish (*i.e.*, sheepshead minnow, bleak, and inland silverside). The Protocol requires that at least one fish is a temperate species. The sheepshead minnow is native to eastern U.S. coastal waters as far north as Massachusetts, and so would be considered temperate. The invertebrate data requirement was met by four species of invertebrates from two classes (Maxillopoda and Malacostraca) of the phylum Arthropoda. The Protocol requires at least one temperate marine invertebrate species. The mysid *Neomysis mercedis* is native to Californian coastal waters, and so would be considered temperate.

3.3.3 Guideline Derivation

The data quantity requirements of the Protocol could be met only by including the Unacceptable data in Table 5. The Protocol methodology was used with this extended dataset to calculate a "Preliminary" marine aquatic life guideline. The Protocol defines procedures for deriving guidelines from chronic or acute data. Only acute data were available in the marine aquatic dataset.

According to the Protocol, a guideline can be calculated from acute data by using the lowest LC50 or EC50 value, and multiplying by an "application factor" of 0.01 for persistent variables. The lowest LC50 in the acute dataset is 44 mg/L for *Mysidopsis bahia* survival (Boeri et al., 1994). Multiplying this value by an application factor of 0.01 gives a Preliminary guideline of 0.44 mg/L (Table 2).

3.4 Irrigation Guideline

No studies were available on the toxicity of MTBE to terrestrial plants. Accordingly, no irrigation guideline for MTBE could be developed.

3.5 Livestock Watering Guideline

3.5.1 Toxicological Behaviour and Effects

Available data on the toxicity of MTBE to mammalian species is summarized in Table 6. No data on the toxicity of MTBE to livestock species was available. The mammalian toxicity data available for MTBE uses laboratory animals (rats, mice, and rabbits) as test species.

3.5.2 Data Analysis

Livestock watering guidelines were developed using the Protocol ("*Protocols for Deriving Water Quality Guidelines for the Protection of Agricultural Water Uses*, CCME, 1999). This Section summarizes the requirements of the Protocol and discusses the available dataset in terms of these requirements. The toxicological dataset was summarized in Table 6.

Protocol requirements for Interim guidelines include toxicological data for at least two studies on two or more mammalian species raised in Canada, including at least one livestock species, and for at least one study on one or more avian livestock species raised in Canada. The dataset summarized in Table 6 does not include any data on livestock or avian species. Accordingly, the data quantity requirements of the Protocol are not met, and no CCME livestock watering guideline can be derived.

It may, however, be useful to have a Preliminary livestock watering guideline until sufficient livestock toxicological data become available. Accordingly, the most applicable study from Table 6 was used and a guideline was derived based on the methodology in the Protocol.

A livestock watering guideline addresses the issue of chronic ingestion of a contaminant. Accordingly the Robinson *et al.* (1990) study was considered to be the most applicable toxicological study as it used an oral route of exposure (gavage), and was the longest duration (90 days) of such studies. This study has been used by several jurisdictions in the United States as the basis of their human health drinking water criteria (CT DEP, 2000; MA DEP, 1995; NH DHHS, 2000).

3.5.3 Guideline Derivation

A Preliminary livestock watering guideline was developed using toxicological data from Robinson *et al.* (1990) and methodology from the Protocol. The Robinson *et al.* (1990) study was subchronic because of its 90-day duration.

The first step in the guideline derivation process outlined in the Protocol is the Tolerable Daily Intake (TDI) calculation (CCME, 1999):

$$TDI\ (mg/kg-bw/day) = \left(\frac{(LOAEL \cdot NOAEL)^{0.5}}{UF} \right)$$

Where: TDI = tolerable daily intake (1.73 mg/kg-bw/day);
LOAEL = lowest adverse effect level (300 mg/kg-bw/day, Table 6);
NOAEL = no adverse effect level (100 mg/kg-bw/day, Table 6); and,
UF = uncertainty factor (100; see discussion below).

The 100-fold uncertainty factor was based on a 10-fold factor to extrapolate from subchronic data to chronic, and a 10-fold factor to extrapolate from rodent data to livestock. Based on the above equation, the TDI for MTBE applicable to livestock is 1.73 mg/kg-bw/day.

The next step in the guideline derivation process was to calculate the reference concentration (RC), which represents the Livestock Watering Guideline. The reference concentration is calculated using the body weight and water ingestion rate of a particular species. Dairy cattle were selected to represent livestock, based on a high water consumption relative to their body weight. The equation used was:

$$RC(mg/L) = \left(\frac{TDI \times BW}{WIR} \right)$$

Where: RC = reference concentration (10.91 mg/L; dairy cattle);
TDI = tolerable daily intake (1.73 mg/kg-bw/day; calculated above);
BW = body weight (862 kg for dairy cattle; CCME, 1999); and,
WIR = daily water intake rate (137 L/day for dairy cattle; CCME, 1999).

The calculated RC for dairy cattle was rounded off to 11 mg/L (Table 2). This value represents a concentration below which livestock health is not expected to be impacted.

The Livestock Watering Guideline determined using published rodent data and algorithms in the Protocol is greater than the taste and odour threshold. While it is known that dairy cattle will drink water with taste and/or odour, it is not known if cattle will tolerate the terpene-like odour of MTBE.

4. DATA GAPS

Data gaps in the guideline development process were identified and are presented in the sections below.

4.1 Freshwater Aquatic Life

The available dataset was sufficient to derive an Interim freshwater aquatic life guideline. In order to derive a Full freshwater aquatic life guideline, the following additional Primary data would be required:

- two chronic studies on two freshwater fish species, one of which was a cold water species (*e.g.*, trout);
- one chronic study on an invertebrate species not from the Class Bronchiopoda (*e.g.*, Daphnia); and,
- one study on a freshwater vascular plant or algal species.

4.2 Marine Aquatic Life

The available dataset was insufficient to derive an Interim marine aquatic life guideline. A Preliminary guideline was derived, based on Primary, Secondary, and Unacceptable data. In order to derive an Interim marine aquatic life guideline, the following additional Primary or Secondary data would be required:

- one acute or chronic study on a marine fish species other than the sheepshead minnow; and,
- one acute or chronic test of an invertebrate of a different class from an opossum shrimp.

4.3 Irrigation

No data were available concerning the toxicity of MTBE to plants. The following Primary or Secondary data would be required to derive an Interim irrigation guideline:

- studies on two species of cereals, tame hays, or pasture crops grown in Canada; and,

- studies on two species of plants grown in Canada including two of the following groups: Leguminosae, Compositae, Cruciferacea, Cucurbitaceae, Liliaceae, Solanaceae, Umbelliferae, and Chenopodiaceae.

4.4 Livestock Watering

The available dataset was insufficient to derive an Interim livestock watering guideline. A Preliminary guideline was derived, based on the most applicable data from the available mammalian laboratory animal studies. In order to derive an Interim livestock watering guideline, the following additional Primary or Secondary data would be required:

- acute or chronic studies on two mammalian species raised in Canada, including at least one livestock species; and,
- one acute or chronic study of an avian livestock species raised in Canada.

4.5 Environmental Monitoring Data

There currently exist limited ambient data for MTBE in British Columbia. Monitoring locations should include high-risk areas such as drinking water reservoirs, municipal drinking water supplies, marinas, and decommissioned or operating gas stations know to have underground storage tanks containing reformulated fuel.

MTBE has been detected in stormwater in other areas. A report by ENCON for Environment Canada on Sources and Releases of Toxic Substances in Wastewaters noted that there was no information on MTBE on stormwater releases to Georgia Basin.

5. ANALYTICAL METHODOLOGY

Analysis of water samples for MTBE requires following appropriate procedures that include sample collection, sample preparation, and analytical methods. USEPA methods have not been developed specifically for the analysis of MTBE. The USEPA and other researchers have published data, however, indicating that MTBE can be measured in environmental samples using one of three SW-846 methods. USEPA methods 8015, 8021, and 8260 have been expanded to include MTBE based on the similarity of chemical and physical characteristics and the common occurrence of MTBE with volatile organic hydrocarbons.

5.1 Sample Collection

Collection of water samples for MTBE analysis are based on protocols established for volatile organic compounds such as benzene. Water collection can be conducted using a dedicated bailer, an inertial pump (*e.g.*, Waterra system), or a peristaltic pump. Samples are collected in clean, laboratory-provided 40 mL screw-cap septum vials. The number of vials required by laboratories for analysis varies between two and three 40 mL vials. Following collection, samples are stored at approximately 4° C (*e.g.*, in an ice-filled insulated cooler) and shipped to the laboratory under standard chain-of-custody documentation.

5.2 Sample Preparation

Sample analysis using USEPA methods are conducted in conjunction with specific preparation procedures. Sample preparation methods applicable for MTBE are summarized in Table 7 (after Rhodes and Verstuyft, 1999). For these methods and a water matrix, chemical sample extraction is not required. Purge-and-trap or headspace methods are appropriate, based on the volatile characteristics of MTBE and volatile organic hydrocarbons. Standard sample preparation methods have been developed for analyte separation using gas chromatography (GC).

Purge-and-trap involves the purging of a water sample with an inert gas such as helium. Volatile compounds are purged from the dissolved phase into the gas phase and are collected in a cryogenic trap attached to a GC. The trap is subsequently heated and the sample injected into the GC column.

Headspace analysis involves removal of a specified volume from a 40 mL vial through the septum. The sample vial is then heated and allowed to equilibrate. A specified volume of the headspace gas is withdrawn using a gas-tight syringe and directly injected into the GC column. This method is based on the equilibrium concentration in the gas and water phase according to Henry's Law.

5.3 Analytical Methods

USEPA methods 8015, 8021, and 8260 used for the quantification of aromatic and volatile petroleum hydrocarbons and chlorinated hydrocarbons have been expanded to include MTBE. These methods rely on purge-and-trap or headspace gas chromatography but they differ in the selection of detector. Detection methods for MTBE analysis include: 1) flame ionization detector (FID); 2) photoionization detector (PID); and 3) mass spectrometry (MS). USEPA methods are summarized in Table 8. However, none of these methods has been validated by USEPA for MTBE analysis and very little data have been published on the accuracy and precision of these methods (Uhler and Stout, 2000).

Rhodes and Verstuyft (1999) reviewed USEPA methods 8015, 8021, and 8260 for their suitability for MTBE analysis. The three methods were considered to be comparable in terms of sensitivity, accuracy, and precision. Significant differences were determined with respect to their selectivity. Selectivity describes the level of confidence associated with the identification of a compound using a specific detector. A non-selective detector responds universally to many compounds and is prone to false positive results in the presence of interferences.

The FID (USEPA 8015) is considered non-selective. Compound identification using GC/FID is achieved based on retention time comparison between a standard and a sample. Based on the high probability for interferences and co-elution of non-target compounds with MTBE, there is a high probability of false positive results or an overestimation of the MTBE concentration. Thus, the FID has a poor selectivity (Table 8).

The PID (EPA 8021) is selective for aromatic compounds but also responds to other compounds, including MTBE, depending on the ionization potential of the PID lamp. As for the FID method, compound identification using GC/PID is achieved based on retention time comparison between a standard and a sample. While the PID method greatly reduces interferences, the presence of dissolved gasoline compounds (*e.g.*, saturated hydrocarbons and olefins) can lead to false positive results and/or an overestimation of the MTBE concentration. Thus, the PID has a good selectivity (Table 8).

The MS method (USEPA 8260) identifies compounds based on their mass spectra. Mass spectra are unique patterns determined by molecular size and charge that allow a positive compound identification. Therefore, the MS has an excellent selectivity (Table 8) and, as a result, is not prone to false positive results and/or an overestimation of the MTBE concentration.

The USEPA has not published validation data for the performance of this method. Validation data in Table 9 were published by the US Geological Survey (cited in Rhodes and Verstuyft, 1999)

using a purge-and-trap GC/MS methodology. The reported detection limit was 0.00006 mg/L, which is three orders of magnitude lower than the proposed human drinking water guideline. The accuracy and precision of the purge-and-trap GC/MS methodology is excellent for environmental sampling.

5.4 Recommended Analytical Methodology

The recommended methods for MTBE analysis require the use of GC/MS technology (USEPA, 1997). Methods include USEPA 8260, 8240, 624, and 524.2. The analysis should be performed by a laboratory certified to perform these methods.

The GC/PID method could be used for screening purposes. Confirmatory analysis by GC/MS would be required should a detection occur using GC/PID.

6. CLOSURE

The information presented in this report was produced exclusively for the purposes stated in the Scope of Work. Komex International Ltd. provided these guidelines for the British Columbia Ministry of Environment, Lands & Parks, solely for the purpose noted above, and does not accept any responsibility for the use of the guidelines for any purpose other than intended or to any third party.

Komex International Ltd. has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this report. The methodologies used deriving the guidelines are based on current federal regulatory protocols and current understanding of biological systems, mechanisms of exposure, and toxicological properties of chemicals.

Questions concerning the derivation or use of the guidelines in this report should be directed to Dr. James H. Sevigny.

7. REFERENCES

7.1 General

API (American Petroleum Institute) Publication, 1988. Alcohols and Ethers - A Technical Assessment of their Application as Fuels and Fuel Components, API Publication 4261, 2nd Edition.

API (American Petroleum Institute), 1993. Odour Thresholds Studies Performed with Gasoline and Gasoline Combined with MTBE, ETBE and TAME. Health and Environmental Sciences Department, No. 4592.

ARCO Chemical Company, 1990a. MTBE- A Key Ingredient for Environmentally Cleaner Gasoline.

ARCO Chemical Company, 1990b. High Purity MTBE - Properties, Applications, Storage and handling.

CCME (Canadian Council of Ministers of the Environment), 1991. A Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life. Appendix IX, April 1991.

CCME (Canadian Council of Ministers of the Environment), 1993. Protocols for Deriving Water Quality Guidelines for the Protection of Agricultural Water Uses. Appendix XV, October 1993.

CCME (Canadian Council of Ministers of the Environment), 1999. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg.

Clary, J. J., 1997. Methyl Tert Butyl Ether Systemic Toxicity. *Risk Analysis*, **17**, 661-672.

Environment Canada (Canadian Environmental Protection Act), 1993. Priority Substances List - Methyl tertiary-butyl ether. Government of Canada. Health and Welfare Canada.

Exxon, Material Safety Data Sheet. 1985. Methyl tertiary Butyl Ether. Exxon Chemical Americas, Houston, TX.

Funasaki. N., S. Hada and S. Nieya, 1985. Partition coefficients of aliphatic ethers-molecular surface area approach. Journal of Physical Chemistry, 89, 3406.

Gilbert C.E., and Calabrese E.J., 1992. Developing a standard for methyl butyl ether in drinking water (Chapter 22). *In*: Gilbert CE, Calabrese EJ (*eds.*). Regulating Drinking Water Quality. Lewis Publishers, p.231-252.

Howard, P.H., Boethling, R.S., Jarvis, W.F., Meylan, W.M., and Michalenko, E.M., 1991. Environmental Degradation Rates. Lewis Publishers Inc., Chelsea, MI., 725 p.

http://www.ec.gc.ca/pdb/npri.

Mackay D, Wan YS, Ma KC., 1993. Illustrated handbook of physical-chemical properties and environmental fate for organic chemicals. Volume III: Volatile organic chemicals. Boca Raton, FL: Lewis Publishers.

Mormile, M.R., Liu S., and J.M. Suflita, 1994. Anaerobic biodegradation of gasoline oxygenates: extrapolation of information to multiple sites and redox conditions," Environmental Science & Technology, 28, 1994.

NPRI (National Pollution Release Inventory), 2000. Accessed 10 January 2001.

NRC (National Research Council), 1996. Nutrient Requirements of Beef Cattle. National Academy Press, Washington, DC.

Shen, Y.F., L.J.Y. Yo, S.R. Fitzsimmons, and M.K. Yamamoto, 1997. Threshold Odor Concentrations of MTBE and Other Fuel Oxygenates. Presented at the national meeting of the American Chemical Society, San Francisco, CA.

Squillace, P.J., J.S. Zogorski, W.J. Wilber, and C.V. Price, 1996. Preliminary assessment of the occurrence and possible sources of MTBE in groundwater in the United States, 1993-1994. *Environmental Science & Technology*, 30.

Squillace, P.J. et al., 1997. Review of the environmental behaviour and fate of methyl tert-butyl ether. *Environ. Toxicol. Chem.*, **16**, 1836-1844.

Solsberg, L., 1991. Environmental Impact Assessment Report, MTBE Trans-Shipment Project. Counterspil Resarch Inc., Vancouver, BC.

Suflita, J.M and M.R. Mormile, 1993. Anaerobic biodegradation of known and potential gasoline oxygenates in the terrestrial subsurface. Environmental Science & Technology, 27.

USGS (US Geological Survey) and Environment Canada, 1999. Groundwater Data from the Abbotsford-Sumas Aquifer in Southwestern BC and Northwestern Washington State, February 1997. Tacoma. WA, USGS Open File Report 99-244.

Verschueren, K., 1983. Handbook of Environmental Data on Organic Chemicals. Second edition. New York: Van Nostrand Reinhold. pp. 40-44.

Yeh, C.K. and J.T. Novak, 1995. Anaerobic Biodegradation of Oxygenates in the Subsurface. Presented at the 1995 Petroleum Hydrocarbons & Organic Compounds in Groundwater: Prevention, Detection & Remediation Conference, American Petroleum Institute, Houston, TX.

Young, W.F., H. North, R Crance, T. Ogden, and M. Arnott, 1996. Taste and odour threshold concentrations of potential potable water contaminants. *Water Researc*h, **30**, 331-340.

7.2 Guidelines – Other Jurisdictions

AR DH (Arkansas Department of Health), 2000. MTBE Facts for Arkansas. Arkansas Department of Health, Division of Engineering.

http://www.adeq.state.az.us/environ/waste/ust/download/1001MTBE.pdf

AZ DEQ (Arizona Department of Environmental Quality), 1999. Report on Methyl Tertiary Butyl Ether (MTBE). Arizona Department of Environmental Quality

www.adeq.state.az.us/environ/waste/ust/download/1001MTBE.pdf

CA DHS (California Department of Health Services), 2000. MTBE in California Drinking Water. California Department of Health Services.

http://www.dhs.ca.gov/ps/ddwem/chemicals/MTBE/MTBEindex.htm

CA DHS (California Department of Health Services), 2001. Final Statement of Reasons for Secondary Maximum Contaminant Level for Methyl tert-Butyl Ether and Revisions to the Unregulated Chemical Monitoring List Title 22, California Code of Regulations.

CT DEP (Connecticut Department of Environmental Protection), 2000, Use of Methyl Tertiary Butyl Ether (MTBE) as a Gasoline Additive. Connecticut Department of Environmental Protection. http://www.dep.state.ct.us/air2/MTBE.pdf

DE DNREC (Delaware Department of Natural Resources and Environmental Control), 2000. Appendix II. Developing and RBSL for MTBE in Delaware. Delaware's Online Risk-Based Corrective Action Program, Delaware Department of Natural Resources and Environmental Control

http://sirb.awm.dnrec.state.de.us/UST/d_cap/appendix%2011.html

Delta Environmental Consultants, 2000. MTBE Groundwater Clean-up levels for LUST Sites: Current & Proposed. Cited in USEPA, Office of Underground Storage Tanks webpage: http://www.epa.gov/swerust1/MTBE/MTBEmap.htm

FL DEP (Florida Department of Environmental Protection), 2000. MTBE (Methyl Tertiary-Butyl Ether) Occurrence in Florida Drinking Water Systems. Florida Department of Environmental Protection. www.dep.state.fl.us/water/wf/dw/MTBE.htm

HI DH (Hawaii Department of Health), 1998. Requirement for Sampling and Analysis of Methyl Tertiary-Butyl Ether in Soil to Groundwater at Underground Storage Tank Closure and Release Investigation Sites. Hawaii Department of Health, Environmental Management Division Solids and Hazardous Waste Branch.

www.state.hi.us/doh/eh/shwb/ust/MTBE.pdf

ID DEQ (Idaho Division of Environmental Quality), 1999. An Evaluation of Methyl Tert-Butyl Ether (MTBE) in Groundwater at Leaking Underground Storage Tank Sites. Idaho

Division of Environmental Quality, Watershed and Aquifer Protection Bureau. http://www2.state.id.us/deq/ust/MTBEstal.pdf

IL PCB (Illinois Pollution Control Board), 1994. Environmental Register No. 484. Illinois Issues Draft Drinking Water Advisory for MTBE Contamination. Illinois Pollution Control Board. www.ipcb.state.il.us/PUBLIC/BACK/9407-484.pdf

IN DEM (Indiana Department of Environmental Management), 2000. Methyl Tertiary-Butyl Ether (MTBE) Technical Issues. Indiana Department of Environmental Management Office of Land Quality. www.state.in.us/idem/olq/programs/lust/MTBE_tech.html

KS DHE (Kansas Department of Health and Environment), 1998. LaCrosse Public Water Supply Treated for MTBE. Kansas Environmental News, July, 1998. Kansas Department of Health and Environment. www.kdhe.state.ks.us/opp/ken/ken9807.html#MTBE

LA DEQ (Louisiana Department of Environmental Quality), 2000. Risk Evaluation/Corrective Action Program (RECAP). Louisiana Department of Environmental Quality. www.deq.state.la.us/technology/recap/2000/text-table1.pdf

MA DEP (Massachusetts Department of Environmental Protection), 1995. Justification for Decreasing the ORS Guideline for MTBE in Drinking Water from 0.7 mg/L to 0.07 mg/L, August, 1995. Massachusetts Department of Environmental Protection, Office of Research and Standards. http://www.state.ma.us/dep/ors/files/MTBE70.htm

MD DE (Maryland Department of Environment), 2000. MTBE Update. Maryland Department of Environment. www.mde.state.md.us/was/MTBE.htm

ME DEP (Maine Department of Environmental Protection), 2000. Some Questions and Answers Regarding MTBE. Maine Department of Environmental Protection. http://janus.state.me.us/dep/rwm/publications/MTBEqa.htm

MI DEQ (Michigan Department of Environmental Quality), 2000. MTBE Fact Sheet. Michigan Department of Environmental Quality, Storage Tank Division. http://www.deq.state.mi.us/std/MTBE.pdf

MO DNR (Missouri Department of Natural Resources), 2000. MTBE Summary of Facts. Missouri Department of Natural Resources, Division of Environmental Quality, Division of Geology and Land Survey. http://www.dnr.state.mo.us/MTBE/MTBE.pdf

MT DEQ (Montana Department of Environmental Quality), 2000. MTBE Use in Montana. Montana Department of Environmental Quality, Remediation Division, Petroleum Release Section. http://www.deq.state.mt.us/rem/hwc/Prs/MTBE.htm

NC DENR (North Carolina Department of Environment and Natural Resources), 2000. Groundwater Classification of Standards, Subchapter 2L. North Carolina Department of Environment and Natural Resources. http://gw.ehnr.state.nc.us/2L202.htm

NH DES (New Hampshire Department of Environmental Services), 2000. MTBE in Drinking Water. New Hampshire Department of Environmental Services. NHDES Technical Bulletin WD-WS-3-10. www.des.state.nh.us/ws-3-19.htm

NH DHHS (New Hampshire Department of Health and Human Services), 2000. Technical Support Document: Derivation of Proposed Primary and Secondary Drinking Water Standards for Methyl tert-Butyl Ether in NH Drinking Water Supplies. New Hampshire Department of Health and Human Services, Office of Community and Public Health. www.dhhs.state.nh.us/CommPublicHealth/RiskAssess.nsf/e4b207c440b7e7458525664700 5ce3e7/21fcb6d8e795ffb4852568b70071bde6/$FILE/MTBE.pdf

NJ DHSS (New Jersey Department of Health and Senior Services), 1999. Drinking Water Quality Analyses, March 1996 to June 1999, United Water Toms River. Public Comment Release. New Jersey Department of Health and Senior Services.

http://www.state.nj.us/health/news/uwtrweb.pdf

NV DEP (Nevada Division of Environmental Protection), 1998. NDEP Oxygenated Full Corrective Action Guidance. Nevada Division of Environmental Protection.

www.state.nv.us/ndep/bca/MTBE_doc.pdf

NY DEC (New York Department of Environmental Conservation), 1999. Governor: New York Toughens Water Quality Standards for MTBE, November 9, 1999. New York Department of Environmental Conservation.

www.state.ny.us/governor/press/year99/nov9_99.htm

OR DEQ (Oregon Department of Environmental Quality), 2000. MTBE Fact Sheet. Oregon Department of Environmental Quality.

www.deq.state.or.us/wmc/cleanup/MTBEfctsht.htm

RI DEM (Rhode Island Department of Environmental Management), 1996. Rules and Regulations for Groundwater Quality. State of Rhode Island and Providence Plantations, Department of Environmental Management, Division of Groundwater and Individual Sewage Disposal Systems. www.state.ri.us/dem/REGS/WATER/GWQL8-96.pdf

USEPA (United States Environmental Protection Agency), 1997. Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Methyl Tertiary-Butyl ether (MTBE). United States Environmental Protection Agency, Office of Water. EPA-822-F-97-009.

UT DEQ (Utah Department of Environmental Quality), 1997. Guidelines for Utah's Tier 1 Risk Based Corrective Action: Utah's Guide for Screening Petroleum Contaminated Sites. Utah Department of Environmental Quality, Leaking Storage Tank Program, Division of Environmental Response to Remediation.

www.eq.state.ut.us/eqerr/TANKCONS/Rem_colm.htm

WA DE (Washington Department of Ecology), 2000. Ecology Testing Storage Tank Sites for MTBE contamination. Washington Department of Ecology. News Release, 21 January 2000. www.wa.gov/ecology/pie/2000news/2000-012.html

WI DNR (Wisconsin Department of Natural Resources), 2000. Public Health Groundwater Quality Standard. Wisconsin Department of Natural Resources. www.dnr.state.wi.us/org/water/dwg/gw/gwstdtbl.htm

7.3 Effects on Freshwater Aquatic Life

Alpha Laboratory Services Ltd., 1989. MTBE fish toxicity. Technical Report NO. 2156, September 1989. Cited in Health and Welfare Canada, 1993.

BenKinney, M.T., J.F. Barbieri, J.S. Gross, and P.A. Naro, 1994. Acute Toxicity of Methyl-Tertiary-Butyl Ether to Aquatic Organisms. Stony brook Laboratories Inc., Princeton N.J; abstract, 15th Annual SETAC Meeting, 30 October – 3 November 1994. Cited in UC Davis, 1998.

Environment Canada, 1989. MTBE 96 hr/LC50 test. Pacific and Yukon Region, Contact Person-K. Hebron, September 1989. Cited in Health and Welfare Canada, 1993.

Environment Canada (Canadian Environmental Protection Act), 1993. Priority Substances List - Methyl tertiary-butyl ether. Government of Canada. Health and Welfare Canada.

Geiger, D.L., D.J. Call, and L.T. Brooke, 1988. Acute toxicities of Organic Chemicals to Fathead Minnows (*Pimephales promelas*), Vol 4. Center for Lake Superior Environmental Studies, University of Wisconsin, Superior, WI: 355p.

Gupta, G. and Y.J. Lin, 1995. Toxicity of methyl tertiary butyl ether to *Daphnia magna* and *Photobacterium phosphoreum*. *Bull. Environ. Contam. Toxicol.*, **55**, 618-620.

Health and Welfare Canada, 1993. Priority Substances List Supporting Document Methyl tertiary-Butyl Ether.

Hockett, J.R., 1997a. Acute Toxicity of MTBE (methyl tertiary-butyl ether) to *Daphnia magna* under static-renewal test conditions. Study number 0480-378-003-001, ENSR, Ft. Collins, Colorado, NTIS#: OTS0573643.

Hockett, J.R., 1997b. Acute Toxicity of MTBE (methyl tertiary-butyl ether) to *Ceriodaphnia dubia* under static-renewal test conditions. Study number 0480-378-007-001, ENSR, Ft. Collins, Colorado, NTIS#: OTS0573646.

Hockett, J.R., 1997c. Short-term Chronic Toxicity of MTBE (methyl tertiary-butyl ether) to *Ceriodaphnia dubia* under static renewal test conditions. Study number 0480-378-004-001, ENSR, Ft. Collins, Colorado, NTIS#: OTS0573647.

Hockett, J.R., 1997d. Acute Toxicity of MTBE (methyl tertiary-butyl ether) to the fathead minnow (*Pimephales promelas*) under flow-through test conditions. Study number 0480-378-005-001, ENSR, Ft. Collins, Colorado, NTIS#: OTS0573648.

Hockett, J.R., 1997e. Short-term Chronic Toxicity of MTBE (methyl tertiary-butyl ether) to the fathead minnow (*Pimephales promelas*) under static renewal test conditions. Study number 0480-378-005-001, ENSR, Ft. Collins, Colorado, NTIS#: OTS0573645.

Hockett, J.R., 1997f. Acute Toxicity of MTBE (methyl tertiary-butyl ether) to the rainbow trout (*Onchorhynchus mykiss*) under flow-through test conditions. Study number 0480-378-002-001, ENSR, Ft. Collins, Colorado, NTIS#: OTS0573644.

HUL Chemicals, 1978. MTBE Data Sheet. Information from "Chemische Werke Huls Aktiengesellshaft to Firma nyas Petroleum" Cited in: Health and Welfare Canada, 1993.

Kado, N.Y., Kuzmicky, P.A., Loarca-Pina, G., Mumtaz, M.M., 1998. Genotoxicity testing of MTBE in the Salmonella microsuspension assay and mouse bone marrow micronucleus test. *Mutation Research*, **412**, 131-138. Cited in Werner *et al.*, 2001.

Longo, S.E., 1995. Effects of Methyl-tert-butyl Ether and Naphthalene on the embryo of the Japanese medaka(Orizias latipes). MS Thesis, Graduate School-New Brunswick Rutgers, The State University of New Jersey and The Graduate School of Biomedical Sciences Robert Wood Johnson Medical School, NJ, USA. Cited in Werner *et al.*, 2001.

Paulov, S., 1987. Action of the anti-detonation preparation tert-butyl methyl ether on the model species *Rana temporaria* L. *Biologia (Bratisil)*, **42**, 185-189. (English abstract).

Rousch, J.M., and M.R. Sommerfeld, 1998. Liquid gas partitioning of the gasoline oxygenate methyl tert-butyl ether (MTBE) under laboratory conditions and its effect on growth of selected algae. *Arch. Environ. Contam. Toxicol.*, **34**, 6-11.

Stubblefield, W.A., Hockett, J.R., Christensen, K.P., Steen, A., Grindstaff, J., Rausina, G., Wong, D.C.L., Arnold, W.R., 1998. Derivation of ambient water quality criteria for MTBE: toxicity to selected freshwater organisms. Abstract, 19th Annual SETAC Meeting, 15-19 November 1998, Charlotte, NC, USA. Cited in Werner *et al.*, 2001.

Tarkpea, M. and O. Svanberg, 1982. The acute toxicity of motor fuels to brackish water organisms. *Marine Pollution Bulletin*, **13**, 125-127.

THE, 1989. Biomonitoring results using MTBE. Wheat Ridge. Colorado, THE Consultants, 8pp. Cited in WHO, 1998.

U.C. Davis (University of California at Davis, Aquatic Toxicology Laboratory), 1998. Toxicity of MTBE to Freshwater Organisms. In: Health and Environmental Assessment of MTBE, Report to the Governor and Legislature of the State of California as Sponsored by SB521. University of California.

Veith, G.D., D.J. Call, and L.T. Brooke, 1983. Structure-toxicity relationships for the fathead minnow; *Pimephales promelas*: Narcotic Industrial Chemicals. *Can. J. Fish. Aqua. Sci.*, **40**, 743-748.

Werner, I., C.S. Kroger, L.A. Deanovic, and D.E. Hinton, 2001. Toxicity of methyl-tert-butyl ether to freshwater organisms. *Environmental Pollution*, **111**, 83-88.

WHO (World Health Organization), 1998. Methyl tertiary-butyl ether. WHO Task Group on Environmental Health Criteria for Methyl Tertiary-Butyl Ether, Environmental Health Criteria, v. 206.

7.4 Effects on Marine Life

Adema, D.M.M., 1982. Tests and Desk Studies carried out by MT-TNO during 1980-1981 for Annex II of MARPOL 1973. Delft The Netherlands, Organization for Applied Scientific Research, 51 pp. (Report CL 82/ 1499). Cited in WHO, 1998.

BenKinney, M.T., J.F. Barbieri, J.S. Gross, and P.A. Naro, 1994. Acute Toxicity of Methyl-Tertiary-Butyl Ether to Aquatic Organisms. Stony brook Laboratories Inc., Princeton N.J; abstract, 15th Annual SETAC Meeting, 30 October – 3 November 1994. Cited in UC Davis, 1998.

Bengtsson, B.E., and M. Tarkpea, 1983. The acute aquatic toxicity of some substances carried by ships. *Mar. Pollut. Bull.*, **14**, 213-214.

Boeri, R.L., J.P. Magazu and T.J. Ward, 1994a. Acute toxicity of methyl tertiary butyl ether to the mysid, *Mysidopsis bahia*. Study No. 424-AR. T.R. Wilbury Laboratories, Inc., Massachusetts, 21 pp. Cited in ?

Boeri, R.L., J.P. Magazu and T.J. Ward, 1994b. Acute toxicity of methyl tertiary butyl ether to the sheepshead minnow, *Cyprinodon variegatus*. Study No. 423-AR. T.R. Wilbury Laboratories, Inc., Massachusetts, 17 pp. Cited in ?

Environment Canada (Canadian Environmental Protection Act), 1993. Priority Substances List - Methyl tertiary-butyl ether. Government of Canada. Health and Welfare Canada.

Gupta, G. and Y.J. Lin, 1995. Toxicity of methyl tertiary butyl ether to *Daphnia magna* and *Photobacterium phosphoreum*. *Bull. Environ. Contam. Toxicol.*, **55**, 618-620.

Tarkpea, M. and O. Svanberg, 1982. The acute toxicity of motor fuels to brackish water organisms. *Marine Pollution Bulletin*, **13**, 125-127.

WHO (World Health Organization), 1998. Methyl tertiary-butyl ether. WHO Task Group on Environmental Health Criteria for Methyl Tertiary-Butyl Ether, Environmental Health Criteria v.206.

7.6 Effects on Terrestrial Plants

Newman, L.A., Doty, S.L., Gery, K.L., Heilman, P.E., Muizneiks, I., Shang, T.Q., Siemieniec, S.T., Strand, S.E., Wang, X., Wilson A.M., Gordon, M.P., 1998. Phytoremediation of organic contaminants: A review of phytoremediation research at the University of Washington. *Journal of Soil Contamination* **7**, 531-542.

Schroll, R., Bierling, B., Cao., G. Doerfler, U., Lahaniati, M., Langenbach, T., Scheunert, I., Winkler, R., 1994. Uptake pathways of organic chemicals from soil by agricultural plants. *Chemosphere*, **28**, 297-303.

WHO (World Health Organization), 1998. Methyl tertiary-butyl ether. WHO Task Group on Environmental Health Criteria for Methyl Tertiary-Butyl Ether, Environmental Health Criteria, v. 206.

7.7 Mammalian Toxicology

Akimoto, R., E. Rieger, A.R. Moossa, A.F. Hofmann, and H.E. Wahlstrom, 1992. Systemic and local toxicity in the rat of methyl tert-butyl ether: a gallstone dissolution agent. *J. Surg. Res.*, **53**, 572-577. Cited in WHO, 1998.

Amberg, A., Rosner, E., Dekant, W., 1999. Biotransformation and kinetics of excretion of methyl-tert-butyl ether in rats and humans. *Toxicological Sciences*, **51**, 1.

Arashidani, K., T. Katoh, M. Yoshikawa, M. Kikuchi, J. Kawamoto, and Y. Kodama, 1993. LD_{50} and weight change in organs of mice following intraperitoneal administration of methyl tertiary-butyl ether. *Jpn. J. Ind. Health*, **35**, 404-405. Cited in WHO, 1998.

ARCO, 1987. Methyl tert-butyl ether exposure monitoring study. Channelview, Texas. ARCO Chemical Company, 39pp. Cited in WHO, 1998.

ASTDR (Agency for Toxic Substances Disease Registry), 1994. Toxicological profile for methyl tert-butyl ether.

Belpoggi, F., M. Soffritti, C. Maltoni, 1998. Pathological characterization of testicular tumours and lymphomas-leukaemias, and of their precursors observed in Sprague-Dawlay rats exposed to methyl tertiary-butyl ether (MTBE). *Eur. J. Oncol.*, **3**, 201-206.

Belpoggi F., M. Soffritti, C, Maltoni, 1995. Methyl tertiary-butyl ether (MTBE) - a gasoline additive - causes testicular and lymphohaematopoietic cancers in rats. *Toxicol. Ind. Health*, **11**, 119-149.

Bevan, C., Tyl, R.W., Andrews, L.S., 1997. Developmental toxicity evaluation of methyl tertiary-butyl ether (MTBE) by inhalation in mice and rabbits. *Journal of Applied Toxicology*, **17**, S21.

Bevan, C. Neeper-Bradley, T.L., Andrews, L.S., 1997. Two-generation reproductive toxicity study of methyl tertiary-butyl ether (MTBE) in rats. *Journal of Applied Toxicology*, **17**, S13.

Biles, R.W., R.E. Schroeder, C.E. Holdsworth, 1987. Methyl tertiary butyl ether inhalation in rats: a single generation reproduction study. *Toxicol. Ind. Health*, **3**, 519-534. Cited in WHO, 1998.

Bird, M.G. Burleigh-Flayer, H.D. Andrews, L.S., 1997. Oncogenicity studies of inhaled methyl tertiary-butyl ether (MTBE) in cd-1 mice and f-344 rats. *Journal of Applied Toxicology*, **17**, S45.

Borghoff, S.J., Murphy, J.E., Medinsky, M.A., 1996. Development of a physiologically based pharmacokinetic model for methyl tertiary-butyl ether and tertiary-butanol in male fischer-344 rats. *Fundamental and Applied Toxicology*, **30**, 264.

Burleigh-Flayer, H.D., J.S. Chun, and W.J. Kintigh, 1992. Methyl tertiary butyl ether: vapor inhalation oncogenicity study in CD-1 mice (Laboratory project ID 91N0013A). Export, Pennsylvania, Bushy Run Research Center. Report to the Methyl Tertiary Butyl Ether Committee, Washington, DC. 1068pp. Cited in WHO, 1998.

Clary, J.J., 1997. Methyl tertiary butyl ether systemic toxicology. *Risk Analysis*, **17**, 661-672.

Chun, J.S., H.D. Burleigh-Flayer, and W.J. Kintigh. 1992. Methyl tertiary butyl ether: Vapor inhalation oncogenicity study in Fischer 344 rats (unpublished material). Prepared for the MTBE Committee by Bushy Run Research Center, Union Carbide Chemicals and Plastics Company Inc. Docket No. OPTS- 42098.

Conaway, C.C., R.E. Schroeder, and N.K. Snyder, 1985. Teratology evaluation of methyl tertiary butyl ether in rats and mice. *J. Toxicol. Environ. Health*, **16**, 797-809. Cited in WHO, 1998.

Daughtrey, W.C., Gill, M.W., Andrews, L.S., 1997. Neurotoxicological evaluation of methyl tertiary-butyl ether in rats. *Journal of Applied Toxicology*, **17**, S57.

Dodd, D.E. and W.J. Kintigh. 1989. Methyl tertiary butyl ether (MTBE): Repeated (13-week) vapor inhalation study in rats with neurotoxicity evaluation (unpublished material). Prepared for the MTBE Committee by Bushy Run Research Center, Union Carbide Chemicals and Plastics Company Inc. TSCATS 403187. EPA/OTS No. FYI-OTS-0889-0689.

Dourson, M.L., and Felter, S.P., 1997. Route-to-route extrapolation of the toxic potency of MTBE. *Risk Analysis*, **17**, 717-726.

Environment Canada (Canadian Environmental Protection Act), 1993. Priority Substances List - Methyl tertiary-butyl ether. Government of Canada. Health and Welfare Canada.

Gilbert C.E., and Calabrese E.J., 1992. Developing a standard for methyl butyl ether in drinking water (Chapter 22). *In*: Gilbert CE, Calabrese EJ (*eds.*). Regulating Drinking Water Quality. Lewis Publishers, p.231-252.

Gill, M.W., 1989. Methyl tertiary butyl ether single exposure vapor inhalation neurotoxicity study in rats. Export, Pennsylvania, Bushy Run Research Center. Report No. 52-533 to the Methyl Tertiary Butyl Ether Committee, Washington, D.C., 116 pp. Cited in WHO, 1998.

Greenough, R.J., P. McDonald, P. Robinson et al. 1980. Methyl tertiary-butyl ether (Driveron) three-month inhalation toxicity in rats (unpublished material). Prepared for Chemische Werke Huls AG, West Germany, by Inveresk Research International. TSCATS/303353. EPA/OTS No. 86-870000172.

Health and Welfare Canada, 1993. Priority Substances List Supporting Document Methyl tertiary-Butyl Ether.

Hutcheon, D.E., Arnold, J.D., Boyle III, J., 1996. Disposition, metabolism, and toxicity of methyl tertiary butyl ether, an oxygenate for reformulated gasoline. *Journal of Toxicology and Environmental Health*, **47**, 453.

Industrial Bio-Test Laboratories, 1969. Acute toxicity studies on X-801-25. Northbrook, Illinois. Report No. A6809 to Sun Oil Company. 27pp. Cited in WHO, 1998.

IITRI, 1992. 28-day oral (gavage) toxicity of methyl tert-butyl ether (MTBE) in rats (Project No. L08100). Chicago, Illinois, Illinois Institute of Technology Research, 48pp. Cited in WHO, 1998.

Lington, A.W., Dodd, D.E., Andrews, L.S., 1997. Evaluation of 13-week inhalation toxicity study on methyl t-butyl ether (MTBE) in Fischer 344 Rats. *Journal of Applied Toxicology*, **17**, S37.

Marsh, D.F. and C.D. Leake, 1950. The comparative anesthetic activity of the aliphatic ethers. *Anesthesiology*, **11**, 455-463. Cited in WHO, 1998.

McKee, R.H., Vergnes, J.S., and Andrews, L.S., 1997. Assessment of the in vivo mutagenic potential of methyl tertiary-butyl ether. *Journal of Applied Toxicology*, **17**, S31.

Mennear, J.H., 1997. Carcinogenic studies on MTBE: critical review and interpretation. *Risk Analysis*, **17**, 673-682.

Miller, M.J., Ferdinandi, E.S., and Kneiss, J.J., 1997. Pharmacokinetics and disposition of methyl t-butyl ether in Fischer-344 Rats. *Journal of Applied Toxicology*, **17**, S3.

Moser, G.J., B.A. Wong, D.C. Wolf, O.R. Moss, and T.L. Goldsworthy, 1996a. Comparative short-term effects of methyl tertiary butyl ether and unleaded gasoline vapor in female B6C3P1 mice. *Fundam. Appl. Toxicol.*, **31**, 173-183. Cited in WHO, 1998.

Moser, G.J., B.A. Wong, D.G. Wolf, R.L. Fransson-Steen, and T.L. Goldsworthy, 1996b. Methyl tertiary butyl ether lacks tumor-promoting activity on N-nitosodiethylamine-initiated B6C3F1 female mouse liver. *Carcinogenesis*, **17**, 2753-2761. Cited in WHO, 1998.

Moser, G.J., Wolf, D.C., and Goldsworthy, L., 1998. Methyl tertiary butyl ether-induced endocrine alterations in mice are not mediated through the estrogen receptor. *Toxicological Sciences*, **41**, 77.

Neeper-Bradley, T.L. 1991. Two-generation reproduction study of inhaled methyl tert-butyl ether in CD Sprague-Dawley rats (unpublished material). Bushy Run Research Center, Union Carbide Chemicals and Plastics Company Inc.

Prescott-Matthews, J.S., D.C. Wolf, B.A. Wong, and S.J. Borghoff, 1997. Methyl tert-butyl ether causes α2u-globulin nephropathy in male Fischer-344 rats. *Toxicol. Appl. Pharmacol.*, **143**, 301-314.

Reese, E., and Kimbrough, R., 1993. Acute toxicity of gasoline and some additives. *Environmental Health Perspectives Supplements*, **101**, 115-131.

Robinson, M., R.H. Bruner, and G.R. Olson, 1990. Fourteen- and ninety-day oral toxicity studies of methyl tertiary-butyl ether in Sprague-Dawley rats. *J. Am. Coll. Toxicol.*, **9**, 525-539.

Snamprogetti, 1980. MTBE toxicological data book. Rome, Snamprogetti Engineering Company S.P.A. Report No. LICE/0086/AA/1g. 202pp. Cited in WHO, 1998.

Stern, B.R., and Tardiff, R.G., 1997. Risk characterization of methyl tertiary butyl ether (MTBE) in tap water. *Risk Analysis*, **17**, 727-744.

Tyl, R.W., 1989. Developmental toxicity study of inhaled methyl tertiary butyl ether in New Zealand White rabbits. Export, Pennsylvania, Bushy Run Research Center. Report No. 51-628 to the Methyl Tertiary Butyl Ether Toxicology Committee, Washington, DC. 260pp. Cited in WHO, 1998.

Tyl, R.W. and T.L. Neeper-Bradley, 1989. Developmental toxicity study of inhaled methyl tertiary butyl ether in DC-1 mice. Export, Pennsylvania, Bushy Run Research Center. Report No. 52-526 to the Methyl Tertiary Butyl Ether Toxicology Committee, Washington, DC. 342pp. Cited in WHO, 1998.

U.S. Department of Health & Human Services, 1995. Toxicological Profile for Methyl T-Butyl Ether. Draft for Public Comment.

USEPA (US Environmental Protection Agency), 1993. Assessment of Potential Health Risks of Gasoline Oxygenated with Methyl Tertiary Butyl Ether (MTBE). Office of Research and Development, EPA/600/R-93/206.

Ward, J.B., W.W. Au, E.B. Whorton, and M.S. Legator, 1994. Genetic toxicology of methyl tertiary butyl ether. Galveston, Texas, University of Texas. Final Report to the Agency for Toxic Substances and Disease Registry. Pp 57-134. Export, Pennsylvania, Bushy Run Research Center. Report No. 52-526 to the Methyl Tertiary Butyl Ether Toxicology Committee, Washington, DC. 342pp. Cited in WHO, 1998.

WHO (World Health Organization), 1998. Methyl tertiary-butyl ether. WHO Task Group on Environmental Health Criteria for Methyl Tertiary-Butyl Ether, Environmental Health Criteria v.206.

Williams, T.M., Cattley, R.C., Borghoff, S.J., 2000. Alterations in Endocrine Responses in Male Sprague-Dawley Rats following Oral Administration of Methyl tert-Butyl Ether. *Toxicological Sciences* **54**, 168.

Yoshikawa, M., Arashidani, K., Katoh, T., Kawamoto, T., Kodama, Y., 1994. Pulmonary elimination of methyl tertiary-butyl ether after intraperitoneal administration in mice. *Archives of Toxicology*, **68**, 517-519.

7.8 Avian Toxicity

No references identified in our search.

7.9 Analytical

Rhodes, I.A.L. and Verstuyft, A.W., 1999. Selecting Methods for the Determination of Oxygenates in Environmental Samples and Gasoline. API Environmental Monitoring Workgroup. www.api.org/ehs/MTBElink.htm

Uhler, A.D. and Stout, S.A., 2000. Considerations for the Accurate Chemical Analysis of MTBE and Other Gasoline Oxygenates. Soil Sediment & Groundwater – MTBE Special Issue, 2000.

USEPA (United States Environmental Protection Agency), 1997. Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Methyl Tertiary-Butyl ether (MTBE). United States Environmental Protection Agency, Office of Water. EPA-822-F-97-009.

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TABLES

Table 1. Chemical and Physical Properties of MTBE

Property	*Value*	*Unit*	*Reference*
Structural formula	$CH_3OC(CH_3)_3$	----	----
Molecular weight	88.15	g/mol	calculated
Melting point	-108	°C	ARCO, 1990a
Boiling point	55.0	°C	ARCO, 1990a
Specific gravity (20/4 °C)	0.744	----	API, 1988; ARCO, 1990b
Density (20 °C)	0.74	g/mL	ARCO, 1990a
Aqueous solubility (20 °C)	40 - 43	g/L	Exxon, 1985
Vapour pressure (25 °C)	33	kPa	Ambrose *et al.*, 1976
Solubility in gasoline	miscible	----	Squillace *et al.*, 1996
log Kow	1.1	----	Gilbert and Calabrese, 1992
log Koc	0.94	----	Funasaki *et al.*, 1985
Henry's law constant (25 °C)	0.0184	unitless	USEPA, 1986
Henry's law constant (5 °C)	0.0197	unitless	calculated
Conversion factor (in air)	1 ppm = 3.658 mg/m3	----	Verschueren, 1983
Flash point	-30.0	°C	ARCO, 1990b
Odour in air	terpene-like	----	Gilbert and Calabrese, 1992
Odour threshold	53	ppb	API, 1993
	15	ppb	Young *et al.*, 1996
	13.5 to 43.5	ppb	Shen *et al.*, 1997
Taste threshold	39	ppb	API, 1993
	40	ppb	Young *et al.*, 1996

Table 2. Proposed Water Quality Guidelines for MTBE

	Water Use					
	Human Drinking Water (mg/L)	Recreational (mg/L)	Freshwater Aquatic Life (mg/L)	Marine Aquatic Life (mg/L)	Irrigation (mg/L)	Livestock Watering (mg/L)
Guideline	0.02	0.02	3.4	0.44	----	11
Basis	taste/odour	taste/odour	toxicity	toxicity	no data	toxicity
Status	Adopted from USEPA (1997)	Adopted from USEPA (1997)	Interim	Preliminary[2]	no data	Preliminary[2]

1. These guidelines are based on a review of values used in other jurisdictions that have developed guidelines.
2. Insufficient data was available to satisfy CCME protocol requirements for an Interim guideline. Guideline is designated "Preliminary".

Table 3. MTBE Drinking Water Guidelines from Other Jurisdictions

State	Guideline (mg/L)	Basis	Reference
USEPA	**0.02 to 0.04**	**Taste and Odour**	**USEPA, 1997**
California	0.005	Secondary MCL	CA DHS, 2000
Texas	0.015	Taste and Odour	Delta Environmental Consultants Inc., 2000
Hawaii	0.020	Taste and Odour	HI DH, 1998
Nevada	0.020	Taste and Odour	NV DEP, 1998
Oregon	0.020	Taste and Odour	OR DEQ, 2000
Kansas	0.020	b	KS DHE, 1998
Maryland	0.020	b	MD DE, 200
Washington	0.020	b	WA DE, 2000
Montana	0.030	b	MT DEQ, 2000
Michigan	0.040	Taste and Odour	MI DEQ, 2000
Missouri	0.040	b	MO DNR, 2000
Rhode Island	0.040	b	RI DEM, 1996
Florida	0.050	Taste and Odour	FL DEP, 2000
Delaware	0.180	Taste and Odour	DE DNREC, 2000
New York	0.010	Carcinogen	NY DEC, 1999
California	0.013	Carcinogen	CA DHS, 2000
Maine	0.035	Carcinogen	ME DEP, 2000
Massachusetts	0.070	Carcinogen	MA DEP, 1995
New Hampshire	0.070	Carcinogen	NH DES, 2000
New Jersey	0.070	Carcinogen	NJ DHSS, 1999
Arizona	0.035	Non-Carcinogen	AZ DEQ, 1999
Idaho	0.052	Risk-based Screening Level	ID DEQ, 1999
Illinois	0.070	Non-Carcinogen	IL PCB, 1994
Connecticut	0.100	Non-Carcinogen	CT DEP, 2000
Utah	0.200	Risk-based Screening Level	UT DEQ, 1997
Louisiana	0.520	Non-Carcinogen	LA DEQ, 2000
Alabama	0.020	a	Delta Environmental Consultants Inc., 2000
Oklahoma	0.020	a	Delta Environmental Consultants Inc., 2000
Pennsylvania	0.020	a	Delta Environmental Consultants Inc., 2000
Ohio	0.040	a	Delta Environmental Consultants Inc., 2000
South Carolina	0.040	a	Delta Environmental Consultants Inc., 2000
Vermont	0.040	a	Delta Environmental Consultants Inc., 2000
Indiana	0.045	a	IN DEM, 2000
Wisconsin	0.060	a	WI DNR, 2000
New Mexico	0.100	a	Delta Environmental Consultants Inc., 2000
North Carolina	0.200	a	NC DENR, 2000
Wyoming	0.200	a	Delta Environmental Consultants Inc., 2000
Colorado	-	Site-specific levels	Delta Environmental Consultants Inc., 2000
Virginia	-	Site-specific levels	Delta Environmental Consultants Inc., 2000
Alaska	-	Waiting for USEPA	Delta Environmental Consultants Inc., 2000
Arkansas	-	Waiting for USEPA	AR DH, 2000
Georgia	-	Waiting for USEPA	Delta Environmental Consultants Inc., 2000
Iowa	-	Waiting for USEPA	IA DNR, 2000
Kentucky	-	Waiting for USEPA	Delta Environmental Consultants Inc., 2000
Minnesota	-	Waiting for USEPA	Delta Environmental Consultants Inc., 2000
Mississippi	-	Waiting for USEPA	Delta Environmental Consultants Inc., 2000
North Dakota	-	Waiting for USEPA	Delta Environmental Consultants Inc., 2000
South Dakota	-	Waiting for USEPA	Delta Environmental Consultants Inc., 2000
Tennessee	-	Waiting for USEPA	Delta Environmental Consultants Inc., 2000
West Virginia	-	Waiting for USEPA	Delta Environmental Consultants Inc., 2000

NOTES:

a. indicates information unavailable

b. indicates presumed to be based on USEPA (1997) Drinking Water Advisory

Table 4. Toxicity of MTBE to Freshwater Aquatic Life

Type of Study	Taxonomic Group	Common Name	Species Name	Duration	Endpoint	NOEC (mg/L)	LOEC (mg/L)	IC25 (mg/L)	LC50	EC50 (mg/L)	Temperature (°C)	pH	Hardness (mg/L)	Alkalinity (mg/L)	Salinity (µS/cm)	Control Survival Reported?	Chemical Analysis?	Test design	Reference
Primary Freshwater Data[1]																			
acute	vertebrate	fathead minnow	*Pimephales promelas*	24 hr	survival					1,045	24-25	7.1-7.6	26-28	26-28	44-66	Y	Y	flow through	Hickett, 1987c
acute	vertebrate	fathead minnow	*Pimephales promelas*	48 hr	survival					1,045	24-25	7.1-7.6	26-28	26-28	44-66	Y	Y	flow through	Hickett, 1987c
acute	vertebrate	fathead minnow	*Pimephales promelas*	96 hr	survival					672	24.7	7.5	47.7	47.5		Y	Y	flow through	Geiger et al., 1988
acute	vertebrate	fathead minnow	*Pimephales promelas*	72 hr	survival					1,026	24-25	7.1-7.6	26-28	26-28	44-66	Y	Y	flow through	Hickett, 1987c
acute	vertebrate	fathead minnow	*Pimephales promelas*	96 hr	survival					988	24-25	7.1-7.6	26-28	26-28	47-68	Y	Y	flow through	Hickett, 1987c
acute	vertebrate	fathead minnow	*Pimephales promelas*	7 days	growth	100	353				24-27	7.4-8.4	92-94	96	132-141	Y	Y	renewal	Hickett, 1987c
acute	vertebrate	fathead minnow	*Pimephales promelas*	7 days	survival	100	354				24-27	7.4-8.4	92-94	96	132-141	Y	Y	renewal	Hickett, 1987c
acute	vertebrate	rainbow trout	*Oncorhynchus mykiss*	24 hr	survival					491	9-13	7.0-7.4	20-24	23-25	50-56	Y	Y	flow through	Hickett, 1987f
acute	vertebrate	rainbow trout	*Oncorhynchus mykiss*	48 hr	survival					493	9-13	7.0-7.4	20-24	23-25	50-56	Y	Y	flow through	Hickett, 1987f
acute	vertebrate	rainbow trout	*Oncorhynchus mykiss*	72 hr	survival					507	9-13	7.0-7.4	20-24	23-25	50-56	Y	Y	flow through	Hickett, 1987f
acute	vertebrate	rainbow trout	*Oncorhynchus mykiss*	96 hr	survival					487	9-13	7.0-7.4	20-24	23-25	50-56	Y	Y	flow through	Hickett, 1987f
acute	invertebrate	water flea	*Daphnia magna*	48 hr	survival					542	19-20	8.2	94	64-65	132-137	Y	Y	renewal	Hickett, 1987g
acute	invertebrate	water flea	*Daphnia magna*	24 hr	survival					1,118	19-20	8.2	94	64-65	134-137	Y	Y	renewal	Hickett, 1987g
acute	invertebrate	water flea	*Ceriodaphnia dubia*	48 hr	survival					510	19-20	8.2	94	64-65	133-137	Y	Y	renewal	Hickett, 1987h
acute	invertebrate	water flea	*Ceriodaphnia dubia*	24 hr	survival					554	19-20	8.2	94	64-65	133-137	Y	Y	renewal	Hickett, 1987h
chronic	invertebrate	water flea	*Ceriodaphnia dubia*	7 days	reproduction	125	247				25-26	7.5-8.7	96	67	131-139	Y	Y	renewal	Hickett, 1991
chronic	invertebrate	water flea	*Ceriodaphnia dubia*	7 days	survival	247	500				25-26	7.5-8.7	96	67	131-139	Y	Y	renewal	Hickett, 1991
Secondary Freshwater Data[1]																			
acute	invertebrate	rotifer	*Brachionus calyciflorus*	24 hr	survival					360	25	nr	nr	nr		Y	Y	static	U.S. Dave Aquatic Toxicology Laboratory, 1998
acute	plant	green algae	*Selenastrum capricornutum*	5 days	growth	100	1,730				22-26	nr	nr	nr		Y	Y	static	Rausch and Schmeltzer, 1998
acute	other	diatom	*Navicula pelliculosa*	5 days	growth	100	1,060				22-26	nr	nr	nr		Y	Y	static	Rausch and Schmeltzer, 1998
acute	other	cyanobacteria	*Synechococcus leopoliensis*	5 days	growth	1,010	1,330				22-26	nr	nr	nr		Y	Y	static	Rausch and Schmeltzer, 1998
Unacceptable Freshwater Data[1]																			
acute	vertebrate	common frog	*Rana temporaria*		survival	1,000	1,000 - 10,000			1,000	?	?	?	?	?	?	?	?	Pleskot, 1987
acute	vertebrate	fathead minnow	*Pimephales promelas*	96 hr	survival					790	24-26	7.5	45.5	47.2		N	Y	flow through	Geiger et al., 1990
acute	vertebrate	Japanese medaka	*Oryzias latipes*	? hr	development	1,000					nr	nr	nr	nr		Y	Y	static	U.S. Dave Aquatic Toxicology Laboratory, 1998
acute	vertebrate	Japanese medaka	*Oryzias latipes*	5 days	development		1,000				?	?	?	?		?	?	?	Kimiga, 1985, cited in Bonner et al., 2001
acute	vertebrate	Japanese medaka	*Oryzias latipes*	1 day	survival		1,000				?	?	?	?		?	?	?	Kimiga, 1985, cited in Bonner et al., 2001
acute	vertebrate	fathead minnow	*Pimephales promelas*	96 hr	survival					250	?	?	?	?		?	N	?	Benkinney et al., 1983
acute	vertebrate	rainbow trout	*Oncorhynchus mykiss*	?	survival					230	?	?	?	?		?	?	?	Benkinney et al., 1984
acute	vertebrate	rainbow trout	*Oncorhynchus mykiss*	96 hr	survival					190	?	?	?	?		?	?	?	Alpha Laboratories, Inc., 1989
acute	vertebrate	rainbow trout	*Oncorhynchus mykiss*	96 hr	survival					193	?	?	?	?		?	?	?	Environment Canada, 1989a
acute	vertebrate	carp	*Leuciscus idus melanotus*	48 hr	survival		1,000 - 2,150				?	?	?	?		?	?	?	HLR Chemicals, 1979
acute	vertebrate	bluegill	*Lepomis macrochirus*	96 hr	survival					354	?	?	?	?		?	?	?	Shubbadeet et al., 1984
acute	invertebrate	water flea	*Daphnia magna*	48 hr	activity level						20	nr	nr	nr	nr	N	N	static	Gupta and Lal, 1995
acute	invertebrate	water flea	*Daphnia magna*	48 hr	survival						20	nr	nr	nr	nr	N	N	static	Gupta and Lal, 1995
acute	invertebrate	water flea	*Daphnia magna*	96 hr	survival					181	?	?	?	?		?	?	?	Benkinney et al., 1983
acute	invertebrate	water flea	*Ceriodaphnia sp.*	48 hr	survival					331	15-21	?	?	?		?	?	?	THE, 1980
acute	plant	green algae	*Selenastrum capricornutum*		EC50 for					184	?	?	?	?		?	?	?	Benkinney et al., 1984
Other Freshwater Data[2]																			
acute	other	bacteria	*Salmonella typhimurium*	48hr	growth		1.5				?	?	?	?		?	?	?	Kado et al., 1986, cited in Wolmes et al., 2001

NOTES

[1] Data are classified as Primary, Secondary, or Unacceptable, based on criteria in CCME (1996). [2] Other Freshwater Data may represent data that may otherwise be classified as Unacceptable, but for which insufficient information is available, or data that are, in fact, acceptable, but for which sufficient information is not available.

a. *Salmonella typhimurium* data may not be representative of the toxicity of MTBE to freshwater aquatic life, and are not included in the guideline derivation process.

nr = not reported.

? = unknown (original article not available at present).

Table 5. Toxicity of MTBE to Marine Aquatic Life

Type of Study	Taxonomic Group	Common Name	Species Name	Duration	Endpoint	NOEC (mg/L)	LOEC (mg/L)	IC25 (mg/L)	LC50/ EC50 (mg/L)	Temperature (°C)	pH	Hardness	Alkalinity (meq/L)	Salinity	Control Survival Reported?	Chemical Analysis?	Test design	Reference
Primary Marine Data [1]																		
acute	invertebrate	opossum shrimp	*Neomysis mercedis*	96 hr	survival				763	13.8 to 21.2	8.1 to 8.2	nr	nr	EC: 2134 to 2196 unfiltered	Y	Y	renewal	U.C Davis Aquatic Toxicology Laboratory, 1998
acute	invertebrate	opossum shrimp	*Neomysis mercedis*	96 hr	survival				663	13.8 to 20.1	8.0 to 7.9	nr	nr	EC: 2518 to 2980 unfiltered	Y	Y	renewal	U.C Davis Aquatic Toxicology Laboratory, 1998
acute	invertebrate	opossum shrimp	*Neomysis mercedis*	96 hr	survival				2.60	20.1 to 28.4	8.1 to 7.8	nr	nr	EC: 2500 to 2650 unfiltered	Y	Y	renewal	U.C Davis Aquatic Toxicology Laboratory, 1998
Secondary Marine Data [1]																		
acute	vertebrate	bighead minnow	*Cyprinodon variegatus*	96 hr	survival	2,500			>2,500	21.1 to 22.5	7.6 to 8.0	nr	nr	20 ppt	Y	N	renewal	Boen et al., 1994
acute	invertebrate	opossum shrimp	*Neomysis mercedis*	96 hr	survival				6.05	20.1 to 28.9	7.9 to 8.0	nr	nr	EC: 2250 to 2770 unfiltered	Y	N	renewal	U.C Davis Aquatic Toxicology Laboratory, 1998
acute	invertebrate	opossum shrimp	*Mysidopsis bahia*	96 hr	survival	15			44	24.1 to 26.4	7.6 to 7.9	nr	nr	20 ppt	Y	N	renewal	Boen et al., 1994
Unacceptable Marine Data [1]																		
acute	vertebrate	tilapia	*Alburnus alburnus*	96 hr	survival				>1,000	>20	7.9	air	1.5	7 ppt	N	N	static	Bengtsson and Tarkpea, 1983
acute	vertebrate	tilapia	*Alburnus alburnus*	24 hr	survival				1700-1800	>20	7.9	air	1.5	7 ppt	N	N	static	Tarkpea and Svanberg, 1982
acute	invertebrate	harpacticoid copepod	*Nitocra spinipes*	96 hr	survival				>1,000	20-22	7.8	air	1.5	7 ppt	N	N	static	Bengtsson and Tarkpea, 1983
acute	invertebrate	harpacticoid copepod	*Nitocra spinipes*	96 hr	survival				>10,000	20-22	7.9	air	1.5	7 ppt	N	N	static	Tarkpea and Svanberg, 1982
acute	vertebrate	inland silverside	*Menidia beryllina*	96 hr	survival				573							Y		BenKinney et al., 1994
acute	invertebrate	opossum shrimp	*Mysidopsis bahia*	96 hr	survival				130							Y		BenKinney et al., 1994
acute	invertebrate	amphipod	*Chaetogammarus marinus*	96 hr	survival		553 (LC10)											Aserna, 1982
Other Marine Data [1]																		
acute	other	Monera [2]	*Photobacterium phosphoreum*	5 min	light output				40		8	air	air	air	N	N	static	Gupta and Lui, 1993
acute	other	Monera [2]	*Photobacterium phosphoreum*	15 min	light output				51		8	air	air	air	N	N	static	Gupta and Lui, 1993

NOTES:

1. Data are classified as "primary," "secondary," or "unacceptable," based on criteria in CCME (1996). Unacceptable data may represent studies that are otherwise acceptable, but for which insufficient information was available.
2. Monera data may not be representative of the toxicity of MTBE to marine life, and are not included in the guideline derivation process.

nr = not reported

** = unknown endpoint, which may or may not be relevant at present*

Table 6. Toxicity of MTBE to Mammalian Species

Type	Species	Concentration or Dose	Effect	Observation	Duration	Test design	Fortification	Test Concentrations	Control Survival	Reference	Available?	Notes
Selected Study - Oral (Gavage) Exposure												
subchronic	Sprague-Dawley Rat	100 - 400 mg/kg-day	NOAEL: 100 LOAEL: 400 increased relative kidney weights in females	gavage; anesthetic effect at 1250 mg/kg-day in two hours; decreased BUN and cholesterol at all doses in females; increased weight of both kidney weights in males at 800 and 1250; increase in relative kidney and liver weights at 800 and 1250; increased relative kidney weights in females at 400, 800, 1250; increase in relative liver, thyroid and cardiac weights in females at 800; chronic nephropathy in control and 1250 males; granular casts and eosinophil cytoplasmic hyaline droplets in proximal tubular epithelial cells in males at 1250	90 days				Robertson et al., 1990	Y	Toxic (Kidney) Toxic (Liver)
Oral/Gavage Exposure												
subchronic	Sprague-Dawley Rat	50 - 440 mg/kg-day	NOAEL: 1750 LOAEL: No adverse systemic and renal toxicity effects	seven rats died accidentally (5 females at 40, 1 male and 1 females at 1750). Transitory salivation at all doses. Transitory hypoactivity/ataxia at 440 and 1750; no effect on body weight or body weight gain; increase in cholesterol in 1750 males and females; no gross necropsy observations; relative liver weights increased in males and females at 1750; increase in relative adrenal weight in males at 1750; increase in relative kidney weights in males at 440 and 1750 and in females at 50 and 1750 (dose related increase). Hyaline droplet formation in proximal convoluted tubules in kidneys of 440 and 1750 males.	28 days			50, 440, 1750 mg/kg-day		Robertson et al., 1992	Y (see path report)	Toxic (Kidney) Toxic (Liver)
subchronic	CD-1 Mice	1000 mg/kg-day	NOAEL for reproductive and conceptive effects	no change in sperm number, particle size, sperm motion, spermatocyte, and capped spermatids in males; no change in estrus, ovaries or fetuses; no mutation effect; in the hypocalciform gastric glandular tissue (Mel) tissue, inverse dose relationship for chromosome aberrations in spleen lymphocytes	5 weeks; 5d/week			0 and 1000 mg/kg-d		Ward et al., 1994	Y (see path report)	Toxic (Kidney) Toxic (Liver)
chronic	Sprague-Dawley Rat	357 mg/kg-day	LOAEL for weight(s), chemistry, renal effects, GI, and body weight effects	transient anesthesia at 1428 mg/kg; 4 fatalities at 714 mg/kg (bacterial infection at 1071 and 1428). Diarrhea and reduced body weight gain at all doses. 6 deaths due to gavage. 4 from 1428 dose, other gavage related; due to gavage; absolute and relative female lung weights lower at all doses; males' absolute kidney weights increased in males at all doses; increased relative kidney weights at 1071 and 1428; increased cholesterol in 1428 males and 714 and 1071 females; decreased blood urea nitrogen and creatinine in 1428 females; increased renal cortical tubular hyaline droplet nephropathy in male rats at all doses. 19 1428 males and 25 control males had increased hyaline droplets in the proximal tubular epithelial cells	14 days			0 (corn oil), 357, 714, 1071, 1428 mg/kg-d		Robertson et al., 1990	Y	Toxic (Kidney) Toxic (Liver)
acute	SKH-1 mice	1800 mg/kg-1	LOAEL for changes in hepatic cytochrome activity	body and liver weight were not affected. 30% increase in hepatic cytochrome P450. 4 - 5 fold increase in hepatic 7-pentoxy resorufin o-dealkylase activity (PROD a CYP2B marker). 2 fold increase in hepatic 7-ethoxy resorufin o-dealkylase activity (EROD a CAPE marker). 2 to 5 fold increase in hepatic cell labeling index in the absence of hepatotoxicity. Absence of changes in serum alanine aminotransferase (ALAT) or histological signs of necrosis				0, 1800 mg/kg-d		Kraus et al., 1996a	Y	Toxic (Liver)
acute	Charles River Rat	3800 mg/kg-one	LD50	Hypoactivity, prostration and ataxia, hypothermia, prostration and death; the symptoms were reversible at and within seven days of dosing. Irritation of the stomach and or small intestine in animals that died	7			LD50: 3800, 4000, 4800, 5000, 10000 mg/kg-one		Lethal Dose Study Laboratories, 1988	Y (see path report)	Toxic (Liver)
acute	Rat (strain ?)	3857 mg/kg-one	LD50	CNS depression, slowed RR and respiratory quotient	7					RIPP, 1983	Y (see path report)	Toxic (Liver)
Inhalation Exposure												
chronic	Sprague-Dawley Rat	1436 - 14360 mg/kg-day	NOAEL for general toxicity; NOEL for reproductive effects; LOAEL for reproductive effects (F0 - F1 weight and offspring)	no adverse effects at 1436; decreased food, water, body weight gain, and food consumption in females. Inconclusive lack of overt effect and blood/organ/serum indicated that body weight and body weight gain were reliable at 10700 and up	two generation study			0, 1436, 10700, 28600 mg/m		Nelson Breckley, 1997; Bevan et al., 1997	Y (see path report)	Toxic (Liver)
chronic	Sprague-Dawley Rat	5000 - 10000 mg/kg-day	NOAEL: 5000 LOAEL: 10000 reproductive effects	slightly decreased sperm motility at 5, 2, 0.5, 0.2 hr	one generation, two litter study (F1 females)	7 hr/day, 5 day/wk		0, 5000, 10000, 17000 mg/m		Bevan et al., 1997	Y	Toxic (Liver)
chronic	Fisher 344 Rat	1436 - 14360 mg/kg-day	NOAEL for female rats; no adverse effects on male reproductive capacity	progressive mortality in females and males starting at 14360 mg/kg-day; hepatomegaly, hyaline drop, clear to dark cytoplasm, cytoplasmic vacuolization, centrilobular hypertrophy, karyomegaly, and single cell necrosis in females at 14360 and 28600; increased body weight & body weight gain in males at 1436 and 10700; decreased cholesterol in males at 28600; decreased food consumption & body weight in females at 10700 & 28600; decreased relative adrenal weight in males at 28600; increased incidence & severity of chronic progressive nephropathy in males at 1436 & up; & females at 10700 & 28600; moderately severe renal tubular cell vacuolization & necrosis in females at 28600; increased incidence & severity of glomerulosclerosis, tubular proteinosis, interstitial cystosis, & hyaline droplets in both sexes at 10700 & 28600; moderately severe renal tubular cell vacuolization & necrosis in females at 28600; centrilobular hypertrophy, karyomegaly, and single cell necrosis in females at 28600; mononuclear cell leukemia & hyperplasia & mononuclear cell leukemia in females at 28600; increased incidence of renal tubular cell adenomas & carcinomas & transitional cell carcinomas in urinary bladder adenomas in males at 10700 & 28600; renal tubular cell adenomas only at 10700; ex	105 weeks; Mod. 5d/week	6 hr/day, 5 day/wk (Modified Ashby and Tennekes (1994) Inhalation Model)		0, 1436, 10700, 28600 mg/m		Dun et al., 1992; Bevan et al., 1997	Y	Toxic (Liver)

Table 6 Toxicity of MTBE to Mammalian Species

Type	Species	Concentration or Dose	Effect	Observations	Duration	Test design	Formulation	Test Concentrations	Control Survival	Reference	Available?	Notes
chronic	[illegible]	1440 mg/m³	NOEL for toxicity	increased mortality, ↓ increased mean survival time in mice at 23600; ataxia, blepharospasm, hypoactivity, prostration and lack of startle reflex in both sexes at 23600; decreased body weight and body weight gain in both sexes at 23600; increased liver weight and kidney weight in males at 1430; and increased relative kidney weight in females at 23600; increase in serum cortisterol in male mice at 23600; decrease in urinary pH and increased urine gamma globulin in both sexes at 23600; among dead male mice, higher frequency of urinary bladder [illegible]; increased incidence of liver cysts in both sexes at 23600; increase in hepatocellular hypertrophy in males at 23600; decreased mineralization in [illegible] at 23600; dose related increased incidence of cystic endometrial hyperplasia in females exposed to incidence of hepatocellular adenomas in females at 23600	18 months; 6h/d, 5d/wk	120 exp group, inhalation chambers, control group received filtered air	[illegible]	[illegible]	[illegible]	Huntingdon Research Centre, 1990; Test Lab. 1991	[illegible]	From WHO, 1998
subchronic	[illegible]	1800 / 3600 mg/m³	NOEC / LOEC for hematological (males) and respiratory (females) effects	increase in hemoglobin levels in males at 3600; decrease in [illegible] in males at 3600; lung weights in females at 3600	13 weeks; 6h/d, 5d/wk	10 exp group, exposure chamber	[illegible]	[illegible]	[illegible]	[illegible] et al., 1990	[illegible] report	From WHO, 1998
subchronic	[illegible]	2860 mg/m³	LOEC for hematological (males), hepatic (males), and renal (males) effects. Hyperplasia at 28600 mg/m3	no mortality, hypoactivity at 14330 and 28600, ataxia at 28600, prostration and lacrimation at 28600 and females at 14300 and 28600; decreased body weight in males at 14300; decreased motor activity in males at 28600, decreased motor activity in females at 2860 and 14330; decreased [illegible] in females at 28600; increased [illegible] counts in males at 2860; increased [illegible] in males and females at 28600; No [illegible] effects; increased relative weight of liver and kidneys in males at 2860 and up; and in females at increased relative weight of [illegible] in males and females at 14300 and 28600; no microscopic changes in [illegible] in males at 2860; increase in lymphoid hyperplasia in the submandibular lymph nodes and [illegible] in degree of [illegible] in spleen; and mild increase in [illegible] in the renal proximal tubules in males at 28600	13 weeks; 6h/d, 5d/wk	25/sex/dose	[illegible]	[illegible]	[illegible] gas analyzer, [illegible]	[illegible]	From WHO, 1998
acute	[illegible]	17 000 mg/m³	LOEC for nervous system, reproductive, and hepatic effects	abnormal gait, hypoactivity, decreased muscle tone, [illegible] at 21 000 mg/m³; [illegible] at 17 000 mg/m³; change in body weight, 20% increase in relative liver weight at 17 000 mg/m³ (LOEL 68% decrease in uterine weight at 34 000 mg/m³); 21% decrease in relative ovarian weight at 21 000 mg/m³; mild cytoplasmic hydropic swelling at 68 000 mg/m³; change in [illegible] at 17 000 mg/m³; increase in hepatic microsomal cytochrome P450 at 34 000 mg/m³ (1.5 fold increase at 17 000 mg/m³); at 34 000 mg/m³, 14 fold increase at 21 000 mg/m³, 7.8 fold increase at 17 000 mg/m³, 3.2 fold at 2100, no histological [illegible], no change in [illegible]	1 hr; 21 days; 24h/d, 5 d/wk(?)	4+5 females/group	>68 000 mg/m³	[illegible]	[illegible]	[illegible] et al., 1990a	[illegible]	From WHO, 1998
acute	[illegible]	17 400 mg/m³	LOEC for CNS effects, decreased body weight, and hepatic effects	abnormal gait, hypoactivity, decreased muscle tone, [illegible] at 34 000 mg/m³; [illegible] at 17 400 mg/m³; change in body weight, increase in relative liver weight at 3 400 [illegible] mild centrilobular hypertrophy at 34 000 mg/m³; no change in [illegible] at 17 400 mg/m³	1 hr; 21 days; 6h/d, 5d/wk	5 females/group, inhalation chamber, particulate free control air	>68 000 mg/m³	[illegible] mg/m³	[illegible]	[illegible] et al., 1990a	[illegible]	From WHO, 1998
acute	[illegible]	17 400 mg/m³	LOEC for nervous system and hepatic effects, and decreased body weight	abnormal gait, hypoactivity, decreased muscle tone, [illegible] at 34 000 mg/m³; [illegible] at 17 400 mg/m³; change in body weight at 21 000 mg/m³; increase in relative liver weight at 3 400 and 17 400 mg/m³; mild centrilobular hypertrophy at 34 000 mg/m³; increase in mild hepatic microsomal cytochrome p450s at 34 000 mg/m³ (1.5 fold increase at 17 400 mg/m³, 7.8 fold increase at 21 000 mg/m³, 14 fold increase at 34 000 mg/m³); no [illegible] in the hepatic cell labelling index at 34 and 17 400 mg/m³; no change in serum [illegible]	1 hr; 21 days; 6h/d, 5d/wk	5 females/group, inhalation chamber, particulate free control air	>68 000 mg/m³	[illegible] mg/m³	[illegible]	[illegible] et al., 1990a	[illegible]	From WHO, 1998
acute	[illegible]	1250 – 5750 mg/m³	NOEC / LOEC for body weight, hepatic, renal (males), and behavioural effects	no mortality, hypoactivity, ataxia, and prostrate inhalation; decreased body weight gain at 13750 and 28330; decreased food consumption at 13750 and 28330; decreased body weight at 13750 and 28330; increased [illegible] in females at 13750 and 28330; increased relative weight of [illegible] in males at 13750 and 28330; increased relative weight of [illegible] in females at 13750; [illegible] and [illegible] kidney weight in females at 13750 and up	1 day; 6h/d, 5d/wk	1 inhalation chamber	[illegible]	[illegible] mg/m³ (4hr) mg/m³	[illegible]	[illegible] et al., 1990	[illegible]	From WHO, 1998
[illegible]	[illegible]	1250 mg/m³	LOEC for hepatic (females) effects	no mortality, hypoactivity, ataxia, prostrate inhalation; decreased body weight gain at 13750 and 28330; decreased food consumption at 13750 and 28330; increased [illegible] in females at 13750 and 28330; increased relative weight of [illegible] in females at 13750; [illegible] and [illegible] kidney weight in females at 13750 and up	1 day; 6h/d, 5d/wk	1 inhalation chamber	[illegible]	[illegible] mg/m³ (4hr) mg/m³	[illegible]	[illegible] et al., 1990	[illegible]	From WHO, 1998
[illegible]	[illegible]	1750 mg/m³	LOEC for maternal toxicity, embryotoxic and fetal developmental effects	reduced food consumption at 7150 and up, increased mortality at 7150 and up, reduced body weight gain, audible respiration in 6 dams at 7150 and up; [illegible] at 28600	gestation days 6-15	3 females/dose	[illegible]	[illegible] mg/m³ (4hr) mg/m³	[illegible]	[illegible] et al., 1990	[illegible]	From WHO, 1998
[illegible]	[illegible]	1088 / 11 [illegible] 14 300 mg/kg/day	NOEL for maternal toxicity, NOEC for developmental effects, LOEC for maternal effects	reduced body weight gain and food consumption at 14300 and up in dams; increased relative liver weight, decreased corrected gravimetric weight change, and gravid uterine weight at 28600; no significant [illegible] effects	gestation days 6-15	15 females/dose	[illegible]	[illegible] mg/m³ (4hr) mg/m³	[illegible]	[illegible] et al., 1990	[illegible]	From WHO, 1998

Table 6. Toxicity of MTBE to Mammalian Species

Type	Species	Concentration or Dose	Effect	Observations	Duration	Test design	Formulation	Test Concentrations	Control Survival	Reference	Available?	Notes
acute	Rat (strain ?)	5400 mg/m³	LOEC for renal effects in males	proximal tubule necrosis and protein droplet accumulation in males at 5400 and 10760; alpha 2u-globulin immunoreactivity in protein droplets; mild dose related increase in alpha 2u with exposure related increase in cell proliferation; no differences found in females	10 days, 6hrd 7d/week	?	?	0, 5400, 10760	?	Prescott-Mathews et al. 1997	Y?	From WHO, 1998
acute	Sprague-Dawley Rat	9000 mg/m³	NOEL for developmental toxicity	decreased food consumption in 900 and no significant developmental toxicity	gestation days 6-15	25 rats/dose	?	0, 900, 3600, 9000 mg/m³	?	Conaway et al. 1985	Y?	From WHO, 1998
acute	CD-1 Mice	9000 mg/m³	NOEL for developmental toxicity	slightly decreased food and water consumption; slight effect, but not sig.f; no significant developmental toxicity	gestation days 6-15	25 mice/dose	?	0, 900, 3600, 9000 mg/m3	?	Conaway et al. 1985	Y?	From WHO, 1998
acute	CD-1 Mice	3600 - 14300 mg/m³	NOEL / LOEL for developmental and maternal toxicity	clinical signs of toxicity and reduced fetal body weight at 14300 and 28600; reduced body weight, body weight gain, and food consumption; increased number of non-viable implantations; reduced number of viable implantations; and % male fetuses; increased incidence of cleft palate at 28600	gestation days 6-15	30 mice/dose	?	0, 3600, 14300, 28600 mg/m³	?	Tyl and Neeper-Bradley, 1989	? non-pub report	From WHO, 1998
acute	Fischer 344 Rat	2860 mg/m³ 14300 mg/m³	NOAEC/ LOAEC for neurotoxicity	no mortality or clinical toxicity at any concentration; a 1% increased incidence and severity of ataxia and duck walk gait in both sexes for 4000 and 8000ppm; 8000ppm males: lacrimation, decreased muscle tone, decreased rectal temperature, decreased treadmill performance time, increased hind limb splay, FOB alterations, and increased incidence of laboured respiration; 4000 & 8000ppm females: increased incidence of lacrimation, piloerection, ataxia, duck walk gait, decreased rectal temperature, and decreased hind limb grip strength; 8000ppm females: increased incidence of laboured respiration and latency to rotate on inclined screen; increased motor activity at 8000ppm; decreased in 8000ppm in males; no difference in female activity; no alterations at 6 or 24 h after exposure	6 hours	22 of each sex at each dose; inhalation chamber; Behavioral evaluations 1, 6 and 24 h after exposure using functional observational battery (FOB) and analysis of motor activity	?	0, 2860, 14300, 28600 mg/m³ (0, 800, 4000, 8000 ppm)	?	Lee 1989; Daughtrey et al. 1997	Y?	From WHO, 1998
acute	White Mouse (strain ?)	141,000 mg/m³ (1.6 mmol/L)	LC50	median concentration for anesthesia (Al [illegible] 1.2 mmol/L)	15 minutes	whole body exposure; 20 mice/exposure group	?	?	?	Hardin and Leake 1950	Y?	From WHO, 1998
acute	Swiss Mouse	400, 000 mg/m3 (260,600 mg/L)	LC50	EC50 for anesthesia 200 mg/L air (130-300 mg/L); convulsive hyperventilation, hyperactivity, ataxia, loss of righting reflex, clonic and sporadic convulsive seizures	5 minutes	whole body exposure; observation for 48 hours following exposure; 4 males/ exposure group	?	?	?	Toxicological Bio-Test Laboratories, 1980	? non-pub report	From WHO, 1998
acute	Swiss Mouse	5.6 min / 658 mg/L (18%v/v)	LT50 / LC50	death occured within 1 hour	1 to 12 minutes	whole body exposure; 20% v/v in air for 1, 4, 5, 8, 9, 12 minutes / 8, 12, 17, 20, 22, 26% v/v in air for 10 minutes	?	See Test Design	?	Smyth (cited) 1963	? non-pub report	From WHO, 1998
acute	Rat (strain ?)	142,000 mg/m³ (39, 460 ppm)	LC50	eye irritation, incoordination, lachrymation, loss of righting reflex, and death	?	?	?	?	?	Smyth, 1951	? non-pub report	From WHO, 1998
Dermal Exposure												
acute	New Zealand White Rabbit	>10,200 mg/kg-day	LD50	no deaths; no gross pathological alterations at less than moderate at application site	14 days	2 males and 2 females/ dose level	occlusive dressing for 24 h	6.8, 10.2 g/kg bw	?	Toxicological Bio-Test Laboratories, 1980	? non-pub report	From WHO, 1998
acute	Rabbit (strain ?)	>10,000 mg/kg-day	LD50	erythema, edema, scaling, fissuring and necrosis of epidermis in animals that died	?	?	?	?	?	Smyth, 1951	? non-pub report	From WHO, 1998
Injection Exposure												
acute	Sprague Dawley Rat	0.2 ml/kg bw	LD50	intracaval injection caused 100% mortality; intravenous injection caused 58% mortality and paryncheal cell [illegible]; in mortality, the pulmonary injury included congestion, hemorrhage, [illegible]	?	7 males dosed intravenously, 10 males dosed intraperitoneally	?	?	?	Hazleton et al. 1952	Y?	From WHO, 1998
acute	Swiss Mouse	1.4 ml/kg bw	LD50	?	?	8 males/dose	?	1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 5.0 mL/kg bw	?	Toxicological Bio-Test Laboratories, 1980	? non-pub report	From WHO, 1998
acute	Mouse (strain ?)	630 (764-478)	LD50	?	?	10 males/dose	?	0, 50, 250, 500 mg/kg bw	?	Hazleton et al. 1952	Y?	From WHO, 1998
acute	Wistar Rat	5.08 ml/kg bw	LD50	in lethal doses, nervous depression, [illegible] followed by short clonic convulsions, autonomic activity (hypersalivation, [illegible], lacrimation) and respiratory disorders; death occured within 30 minutes; survivors showed no clear symptoms or signs of nervous depression lasting more than [illegible]	?	16 males/dose	?	3.1, 4.2, 5.3, 6.5, 8.75, 12.5, 17.5 mg/kg bw	?	Toxicological Bio-Test Laboratories, 1980	? non-pub report	From WHO, 1998
acute	Wistar Rat	6.7 ml/kg bw (5.75-7.75 ml/kg)	LD50	?	?	8 males/dose	?	3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0 mg/kg	?	Toxicological Bio-Test Laboratories, 1980	? non-pub report	From WHO, 1998
acute	Swiss Mouse	3.6 ml/kg bw (2.93-3.57 ml/kg)	LD50	?	?	8 males/dose	?	1.0, 2.5, 3.0, 4.0, 4.5, 5.0, 5.5 ml/ kg bw	?	Toxicological Bio-Test Laboratories, 1980	? non-pub report	From WHO, 1998

Table 7. Sample Preparation Methods

USEPA SW-846 Method	*Technology*
5030	purge-and-trap
5021	headspace

Summarized from Rhodes and Verstuyft (1999)

Table 8. Summary of Methods Applicable to MTBE Analysis

EPA SW-846 Method	*Detector*	*Target Analytes*	*Comparable EPA Methods*	*Selectivity* [1]
8015	FID	non-halogenated organics	None	Poor
8021	PID	aromatic and halogenated volatiles	8020, 602, 502.3	Good
8260	MS	volatile organic compounds	8240, 624, 524.2	Excellent

[1] *Rhodes and Verstuyft (1999)*

Table 9. Performance of Purge-and-Trap GC/MS Analysis for MTBE in Water

Compound	*Detection Limit (mg/L)*	*Accuracy (% Recovery)*	*Precision (%)*
MTBE	0.00006	97	2.5

Rhodes and Verstuyft (1999)